A C Redfield

(Courtesy U. S. Fish and Wildlife Service)

Underwater photograph of the Nassau Grouper (*Epinephelus striatus*).

MARINE PRODUCTS OF COMMERCE

Their Acquisition, Handling, Biological Aspects and the Science and Technology of Their Preparation and Preservation

BY

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Preface

Twenty-seven years ago the senior author with the help of a number of collaborators wrote the first edition of "Marine Products of Commerce," one of the first treatises in which the technology of all the commercial products of the sea was considered. Great advances have been made in the technology of fishery and other marine products during the past quarter century. Consequently, preparation of this second edition has necessitated rewriting almost the entire book. Only two chapters, those on Sponges and Fish Glue, remain substantially unchanged.

Entirely new industries have arisen since the publication of the first edition, as for example the extraction of magnesium and bromine from sea water and the making of vitamin concentrates from fish-liver oils. Because of the importance of the magnesium and bromine industry, an entire chapter has been devoted to it. The manufacture of chemicals from sea water is an industry that is likely to become more and more important in the future. Our rapidly increasing knowledge of chemistry will make possible the perfection of methods of separating other substances from the sea, the great storehouse of water-soluble chemicals.

Another new industry which is considered in detail in this new edition is the marketing of packaged fish fillets and steaks. The preparation, packaging, freezing and marketing of fish fillets is now one of the most important fishery industries. In 1923 freezing by immersion in or spraying with brine was the only known method of quick-freezing fish. Since then many new and superior methods of rapidly freezing fish and fishery products have been perfected and are now being used. These methods are described and discussed herein.

Great improvements have also been made in equipment used for the transportation of both fresh and frozen fishery products. In 1923 little was known about the refrigeration of motor trucks and trailers. Today immense quantities of fresh and frozen fish and shellfish are shipped in refrigerated trucks which often transport these products a thousand miles or more. Because of the importance of the refrigerated transport of perishable fishery products in making available fish and shellfish of excellent quality throughout the United States and Canada, an entire new chapter is devoted to this subject.

The marine algae or seaweed industry has also been undergoing startling changes. In 1923, seaweeds were used principally for human food and agar in the Orient, for the making of iodine and potash in Norway, Japan and a few other countries, for fertilizer and for stock food. Since then the making of iodine and potassium salts from seaweeds has become almost a thing of the past. On the other hand, the manufacture and use of seaweed extractives has become an important industry in America and certain parts of Europe. Irish moss extractives and alginates, prepared from laminaria and giant kelp, are being used extensively in many important food products and for many industrial purposes.

These important new technological developments are presented in the chapters about algae and seaweed products.

Since 1923 our knowledge of the vitamins and amino acids has been greatly extended. Further, we now know a great deal more about the composition and nutritive value of the fish, shellfish and fishery products used for food or medicine. Further, large quantities of liver oils are now used for the making of vitamin concentrates. For these reasons it has been necessary to rewrite and greatly expand the chapters dealing with the nutritive value of fishery products and the technology of fish liver and other oils.

Fish meal has been found to be of greater value for animal feeding than was formerly believed to be the case. Further, certain technological improvements have made possible the production of meals of greater nutritive value. These changes in the industry are indicated in the chapter on fish meal.

References to the original literature, to comprehensive review articles, and to worthwhile books, which will be helpful to those desiring more information than that presented in this book, are appended at the end of each chapter. Literature which was published prior to 1923 is not included unless the paper or treatise is of exceptional importance. Those who wish to search the literature published before 1923 are referred to the First Edition of this book.

The authors make no claim for originality for any of the theories or facts presented. All available sources of information have been freely consulted and compared, and the latest information presented to the reader.

The authors and their collaborators have attempted to have all of the material presented accurate and up-to-date. Undoubtedly, unsuspected errors have crept in. We desire to be advised of any erroneous statements noted, so that future editions may be made more accurate.

The book completed, the more pleasant task remains to thank the many persons who have been so kind as to aid in its preparation. First, the authors wish to thank their collaborators who have done so much to make this book a success.

Special mention should be made of the following persons who have read parts of the manuscript and have given many valuable suggestions for its correction and revision:

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In addition to those named above, many other persons, too numerous to mention, have aided in the work. Many have furnished photographs used as illustra-

tions. Others have given information and indicated where important facts could be learned.

The authors hope that the new book will come up to the expectations of those who have aided in its preparation. If this is accomplished, we will feel that we have made a worthwhile contribution to the literature on marine products.

Donald K. Tressler
James McW. Lemon

October 1950

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CHAPTER 1

The Ocean: Its Potentialities and Products

The area of the surface of the earth is 196,950,277 square miles, of which 139,295,000 square miles, or 70.73 per cent, are occupied by ocean (Lambert 1926). Its average depth has been estimated to be 2.38 miles, and the greatest depth yet found is 6.7 miles (5900 fathoms). Its volume has been calculated to be about 331,000,000 cubic miles. To the casual observer the ocean is a barren waste chiefly used for transportation. Actually, it is teeming with both plant and animal life. The largest animals and the tallest plants grow there, and nowhere else can such large quantities of excellent food be obtained with so little effort.

Potential Resources of the Ocean

Sea water is "water" only in the sense that water is the dominant substance present. Actually, it is a solution of many salts and gases, not to mention a tremendous number of living organisms, most of which are very minute. Throughout the ages there has been a steady movement of materials from the land into the ocean. The greatest addition is enormous quantities of materials, both in solution and in suspension, which are carried by the water in the rivers. It has been estimated that 71,389 cubic miles of sea water evaporate each year and return to the ocean either in the form of rain or water from the rivers. The latter amounts to about 20,900 cubic miles of water annually which brings 2,735,000,000 metric tons of dissolved salts in the ocean (Table 1). In addition, vast quantities of suspended mud and silt are carried by the rivers into the ocean and deposited principally near the mouths of the rivers.

Other agencies which contribute to the salts in the ocean are volcanoes, submarine fissures, fumaroles, springs, glaciers, and even lightning which oxidizes some atmospheric nitrogen to oxides of nitrogen which dissolve in water to form nitric acid, which is then dissolved by rain and eventually reaches the ocean.

The total quantity of soluble salts in the ocean is very great—about 5×10^{16} metric tons * (Sverdrup, Johnson, and Fleming 1946), which is enough to form a layer of dried salts about 500 feet deep over the surface of the dry land.

The composition of sea water has been the subject of many elaborate analytical investigations, which have shown that, although it varies considerably in concentration, the composition of the saline matter which it contains is remarkably uniform. Sea water is mainly a solution of the chlorides and sulfates of sodium, magnesium, calcium, and potassium, although it contains appreciable amounts of bromine, iodine, iron, silicon, carbonate, and phosphate. Other elements which have been found in the salts of sea water include aluminum, manganese, phosphorus, strontium, barium, rhubidium, fluorine, copper, nickel, vanadium, lithium,

* Clarke (1924) estimated the amount to be 46.188×10^{16} metric tons (Table 1).

TABLE 1. COMPARISON OF OCEANIC AND FLUVIATILE SALTS.*

	Annual Addition from Rivers (*millions of metric tons*)	Total Now in Ocean (*millions of metric tons*)
Carbonate (CO_3)	961.350	95,600,000
Sulfate (SO_4)	332.030	3,553,000,000
Chlorine (Cl)	155.350	25,538,000,000
Bromine (Br)	———	86,800,000
Nitrate (NO_3)	24.614	————
Sodium (Na)	258.357	14,130,000,000
Potassium (K)	57.982	510,800,000
Calcium (Ca)	557.670	552,800,000
Magnesium (Mg)	93.264	1,721,000,000
Iron oxide (Fe_2O_3), Aluminum oxide (Al_2O_3)	75.213	————
Silica (SiO_2)	319.170	————
	2,735.000	46,188,000,000

cerium, zinc, yttrium, lanthanum, lead, molybdenum, thorium, caesium, arsenic, scandium, uranium, selenium, mercury, silver, gold, radium, chromium, cobalt, tin, and cadmium. This list merely indicates the present state of our knowledge. Undoubtedly, small amounts of all the elements occur in sea water.

Careful analytical work by many chemists has indicated the composition of sea water on a water-free basis (Table 2). Many other analyses, tabulated by Clarke (1924), of sea water taken from many different parts of the world correspond closely to those cited in the table. Many of the differences in the analyses reported are no greater than might be expected from differences in the analytical methods used.

The volume of the ocean is so great that the total quantity of a given substance may be tremendous, even though the percentage seems very small. Thus, since the volume of the oceans is about 331,000,000 cubic miles, they contain approximately 150 billion tons of a substance occurring only to the extent of one part per billion.

The essential uniformity in composition of the sea salts is evident. Inasmuch as Dittmar's results (A) represent the average composition of 77 samples of sea water, taken from many different parts of the ocean and drawn from various depths of water, these results should be taken as the standard for comparison. Dittmar (1884) found that the salinity of sea water diminishes from the surface to a depth of 800 to 1,000 fathoms, and then increases to the bottom. Around the poles there are areas of concentration because of the freezing of the surface which removes nearly pure water and leaves a large part of the salts behind. Since the rivers continually bring into the ocean small amounts of dissolved mineral matter which is derived from the decomposition of rocks by flowing and percolating waters, it is assumed that the source of the sea salts is the mineral matter of rocks which have been eroded by continual weathering.

* Clarke, F. W., "The Data of Geochemistry," *U. S. Geol. Survey Bull.*, **770,** 5th ed. (1924).

TABLE 2. ANALYSIS OF OCEANIC SALTS
Percentage on water-free basis

	A	B	C	D	E
Chlorine (Cl)	55.292	55.185	55.25	55.46	55.30
Bromine (Br)	0.188	.179			0.16
Sulfate (SO_4)	7.692	7.914	7.56	7.59	7.72
Carbonate (CO_3)	0.207	0.213	0.37	0.30	0.19
Sodium (Na)	30.593	30.260	30.76	30.53	30.51
Potassium (K)	1.106	1.109	1.14	1.12	1.12
Calcium (Ca)	1.197	1.244	1.22	1.21	1.19
Magnesium (Mg)	3.725	3.896	3.70	3.79	3.81
Total	100.000	100.000	100.00	100.00	100.00

A. Dittmar (1884). Mean of 77 analyses of sea water from many localities collected by the *Challenger* expedition (Salinity 3.301 to 3.727 per cent).
B. Makin (1898). Mean of 22 samples of Atlantic water collected on a voyage from the Cape of Good Hope to England (Salinity average 3.631 per cent).
C. Wheeler (1910). Mean of 5 samples of water taken from near Beaufort, N. C. (Salinity 3.179 to 3.607 per cent).
D. Schmelck (1882). Mean of 51 incomplete analyses of water from the North Atlantic between Norway, the Faroe Islands and Iceland and northward to Spitzbergen (Salinity 3.37 to 3.56 per cent).
E. Natterer (1892, 1893, 1894). Average of 42 samples of waters collected during the voyages of the Austrian steamer *Pola* in the eastern Mediterranean (Salinity 3.836 to 4.115 per cent).

The age of the ocean can be determined with some exactness by knowledge of two factors: (1) the total amount of sodium now present in the ocean, assuming that it has been added in a constant manner without serious loss, and (2) the annual amount of sodium added by the rivers. Joly (1900) estimated the age of the ocean by dividing the total estimated amount of sodium by the annual amount contributed by the rivers and obtained 89,222,900 years. Clarke (1924) has discussed Joly's calculations in the light of the most reliable figures obtainable at the present time, and after making allowance for various possible errors, concludes that "the age of the ocean, since the earth assumed its present form, is somewhat less than 100,000,000 years."

Gold, silver, and radium are among the elements contained in sea water. Very small amounts of these elements have been found, and they are ordinarily listed as traces. Nevertheless, their presence in sea water has attracted much attention.

E. Sonstadt (1872) was the first to find a trace of gold in sea water. Numerous observers have verified his observation. C. A. Münster (1892) found 5 to 6 mg of gold and 19 to 20 mg of silver per ton of water from the Kristiania Fjord, Norway. Liversidge (1895) analyzed Australian waters and found gold to the extent of 0.5 to 1.0 grains per ton.

Inasmuch as sea water, salt, and oceanic sediments are all more or less radioactive, various observers have concluded that they contain radium. Joly has estimated that 1 cc of sea water contains on the average 0.017×10^{-12} gram of radium. However, there is no evidence to show that this radioactivity is due solely to radium.

Certain unscrupulous persons have profited from man's cupidity by capitalizing on fake schemes for the extraction of gold and silver from sea water. Carefully conducted studies have shown that it is possible to separate gold from sea water, but that the cost is hundreds of times greater than the value of the gold obtained.

The quantities of the more abundant chemicals found in the entire ocean are so great as to be beyond comprehension. Even the amount of salts in a cubic mile of sea water is almost beyond our understanding, as shown in Table 3.

TABLE 3. THE MORE ABUNDANT COMPOUNDS (HYPOTHETICAL COMBINATIONS) AND ELEMENTS IN ONE CUBIC MILE OF SEA WATER.*

Sodium chloride	128,284,403	tons
Magnesium chloride	17,946,522	"
Magnesium sulfate	7,816,053	"
Calcium sulfate	5,934,747	"
Potassium sulfate	4,068,255	"
Calcium carbonate	578,832	"
Rhubidium	64,316	"
Fluorine	1,400	"
Barium	916	"
Zinc	450	"
Iodine	a minimum of 90	"
Arsenic	46 to 368	"
Phosphorus	up to 400	"
Nitrogen	up to 1300	"

It is noteworthy that, with the exception of oxygen, the most abundant elements in igneous rocks, silicon, aluminum, and iron, are present in only very small amounts in sea water. Thus, the relative abundance of the elements in sea water is far different from that in the earth's crust.

The composition of the dissolved substances in river water is quite different from that of the sea. It is probable that factors operating in the ocean itself, such as solubility, physical-chemical reactions, and biological activity (Sverdrup, Johnson, and Fleming, 1946), control the concentrations of many of the elements that are potentially available in large amounts. The solubility of certain compounds of some elements may limit the concentration of these elements. Additional amounts of these elements brought to the ocean in solution in river water will be removed by chemical precipitation. The quantities of other elements may be limited by physical-chemical processes more complex than the precipitation of some simple salt, as, for example, the reactions that may take place between the dissolved substances and the colloidal and finely divided material introduced by the rivers. Such processes include ionic adsorption, base exchange, and the formation of complex minerals.

Biological activity is undoubtedly of great importance in controlling the concentrations of many of the elements in the ocean. For example, the growth of plants in the surface layers greatly reduces the quantity of nitrates and phosphates; however, these compounds tend to accumulate in the comparatively stagnant abyss. A large proportion of marine animals use phosphate and carbonate of

* Taylor, H. F., "Resources of the Ocean," *J. Franklin Inst.*, **214**, 167–196 (1932).

lime to form their shells or bones and thus remove quantities of carbon dioxide, phosphate, and lime from the sea water. They also absorb nitrogen compounds and oxygen. When these animals die, they decompose, giving off carbon dioxide, ammonium salts, and water. The calcium carbonate and phosphate of their shells and bones are deposited on the ocean floor.

The Chemical Wealth of the Ocean

As the ocean contains an enormous quantity of most of the pure and combined elements, among them valuable inorganic salts, it is surprising that so few of these substances can be obtained for industrial use. At present the only mineral products taken in quantity from sea water are salt, magnesia, magnesium, magnesium salts and other magnesium products, and bromine and small amounts of potassium salts, iodine, and calcium salts.

Is it possible to exploit the vast quantity of valuable chemicals in the ocean? To do so it is necessary to develop new methods which will not require the evaporation of a large proportion of the water. Taylor (1932) has indicated that gold and other heavy metals can be taken from sea water by kaolin or alumina jelly. Perhaps a system of ion exchange may soon be developed which will make possible the recovery of many metals and other inorganic materials of great value.

One of the great industrial developments which occurred during World War II was the large-scale recovery of magnesium from sea water (page 41). In addition, the processes of recovering bromine from sea water were greatly improved. These advances may be the forerunners of other marine chemical industries.

The Ocean Floor

The floor of the ocean is strewn with glacial rocks, fossilized bones and teeth of ancient animals, old shells, sedimentary remains of tiny organisms of silica, iron, and calcium, mixed with sediments and precipitated insoluble matters, and pumice stone and volcanic dust, which in the course of time are compressed to form dense rock. During the centuries the shells, teeth, and bones have become encrusted with deposits of manganese and iron oxides, phosphates, and, in some cases, barium sulfate. The phosphate concretions sometimes contain as much as 20 to 24 per cent P_2O_5.

As sea water is a depository for soluble salts, the floor of the ocean is no less significant as a depository for chemical substances insoluble in water. In fact, the ocean floor records a large part of the geological history of the world.

Biological Aspects

Sea water contains inorganic nutrients in approximately the same proportions to which living things are adapted. It also contains a huge amount of living and dead organic matter (5 mg per liter, or one part in 100,000). Although this may not seem like much, it amounts to 22,800 tons per cubic mile. Some of this organic matter is brought in by the rivers, and much comes from the plants and animals that live in the ocean. When these organisms die, they disintegrate and their body substances diffuse in the water.

The ocean receives nearly 71 per cent of all the radiant energy coming from the sun to the earth's surface. Solar energy is absorbed at and near the surface of the ocean and is used by minute plants, floating mostly in the top 25 fathoms, to

manufacture living substance. They use silica, lime, phosphoric acid, and strontia to form their shells and skeletons, carbon dioxide and water to produce starches, sugars, and fats, and nitrogen, sulfur, phosphorus, iron, iodine, etc. to make the many complex chemicals characteristic of plants.

These minute plants are almost inconceivably numerous and varied. Diatoms, peridinians, brown and blue-green algae, and other microscopic forms of vegetable and animal life, collectively called plankton, constitute the primary manufacturers of food in the ocean. In the spring when the long hours of sunlight give so much radiant energy to the surface of the North Atlantic, the concentration of plankton is high enough to muddy the water. In the English Channel (Taylor, 1932) it has been estimated that 4,000 tons of vegetable matter are produced annually per square mile.

The minute plants are consumed by many different species of small animals, such as snail-like mollusks, shrimplike Crustacea, globigerina, radiolarians, jelly fish, and certain herring-like fish whose gills can strain the plankton out of the water. In an investigation of the herring of the North Sea, Savage (1931) has estimated that the herring which landed at the English east coast fishing ports in 1926 required 109,000 tons of planktonic food. The herring family, including herring, menhaden, shad, sardines, etc., and also mackerel, are consumers of plankton and, consequently, are important because they constitute a source of plankton for the larger fish which cannot use it directly.

Within the plankton population there is a continual struggle for survival against the casualities due to parasitic infestations, bacterial depredations, and excessive change of temperature. The dead and dying plankton tend to settle in enormous numbers at the bottom of the ocean and become food for worms, mussels, scallops, conchs, and other organisms which live there. These in turn become the food of crabs, lobsters, cod, haddock, etc. It is thus evident that both on the surface and at the bottom of the ocean the chain of life, via consumer and consumed, tends to produce organisms large enough to be available to man.

Even the vitamins of cod-liver oil can be traced to their ultimate source in the oil of diatoms which grow and make oil in the sunshine at the surface of the ocean. Ahmad (1930) obtained an oil, similar to cod-liver oil in its chemical and nutritional characteristics, from a pure culture of the diatom, *Nitzschia closterium*. Although little is known concerning the chemistry of plankton, enough is known to show that the planktonic flora and fauna of the ocean collect and concentrate many of the rarer chemical elements. The plankton organism *Podocanelius* makes its skeleton of strontium compounds. Seaweeds and sponges have many times the iodine content of sea water. Haber (1927) found more gold in plankton than in the water. Oysters, which are plankton eaters, contain relatively large amounts of copper, arsenic, manganese, iron, iodine, and numerous other elements.

The ocean is an almost perfect nutrient solution, containing all of the elements necessary for every form of life. Excluding insects, of which there are some 500,000 described species, about four-fifths of all other species of animals known to man live there. Marine animals include more than 40,000 species of mollusks, nearly as many Crustacea, and almost half this number of marine fishes. Of the 48 major classes of animals only insects, reptiles, birds, myriapods, amphibians, and mammals are predominantly terrestrial. Several classes, including ctenophores, porifera, coelenterates, echinoderms, and tunicates, are largely confined to the

ocean. Taking into consideration the great abundance and accessibility of marine life, it is surprising that man makes so little use of it.

Relative Importance of Marine Products

Our only sources of food, upon which life is dependent, are agriculture and fisheries; the wild game of the forests is no longer a factor of economic importance. While the fisheries are nearly overshadowed by agriculture, they furnish products which are almost indispensable. Crops do not need to be sown or cultivated, yet they are extremely productive. Moreover, the annual product has been rapidly increasing in both quantity and value in recent years. The limit of production has not been reached, and with careful supervision the fisheries may be expanded greatly. The most reliable statistics available indicate that the annual products of the world's fisheries are valued at approximately three billion dollars (page 195). At least a hundred million dollars may be added to the total as the value of the salt, magnesium, bromine, pearls, and miscellaneous products is not usually included in the evaluation of the fisheries.

It has been estimated that, taken as a whole, fishery products constitute less than three per cent of the world's food. However, in certain countries, such as Norway and Japan, fish is a much more important food factor and may even make up ten per cent.

In England and the United States the industries are relatively small in comparison with agriculture, mining, and manufacturing. In England the chief fisheries are herring, cod, haddock, and mackerel. The more important catches of fish in American waters include those listed, as well as salmon, sardines, halibut, menhaden, shad, alewives, oysters, shrimp, and lobsters.

In Japan the marine fisheries occupy a place of importance comparable to that of no other large nation. In spite of the small area of land the coast line is extraordinarily long—more than 20,000 miles in extent. Since the islands are rather mountainous, the agricultural products are limited. As there are about 55,000,000 inhabitants in an area of only 260,738 square miles, the Japanese are forced to turn to the ocean for a considerable proportion of their food. Japanese statistics indicate that about 975,000 persons * were entirely or partly engaged in the fisheries in 1945; prior to 1942 the number of Japanese engaged in the fishery industries was approximately 1,450,000. The great number of people in these industries may be accounted for by the fact that every part of Japan is either directly or indirectly concerned with fisheries. The annual product per person engaged in the industry is very low; the total value of fishery products in 1940 was only about $100,000,000, or about $70 per person.

In northern Europe, where farming is more difficult and meat-producing animals scarcer, the fisheries are of greater national importance than in the United States. Fishing is one of the leading industries of Norway and Scotland. In 1948 the Norwegians caught about one million metric tons of herring, having a value of about 173,000,000 kroner. Cod, haddock, flounder, and sardines are also caught in enormous quantities. Furthermore, the Norwegians control about half of the world's whaling industry. Denmark and Iceland, considering their population and size, also have exceptionally important fisheries.

* 523,000 persons were employed full time and about 452,000 devoted part of their efforts to fishing or to the fishery industries.

Newfoundland and Labrador offer one of the best modern examples of a people living from one resource—fish. Fish products, chiefly dried and frozen cod, constitute about eight-ninths of their exports. There is a little iron mining, lumbering, and paper making, but a large proportion of the workers are engaged, either directly or indirectly, in the fisheries. The climate is too cold and damp for much farming. British Columbia produces nearly half the Canadian total of fish products.

Variety of Products

Fish. Fish are marvelously abundant. Thousands of species exist whose names are known only to the systematist. It has been estimated that there are more than 19,000 different species, some of which are as numerous as the menhaden, a billion pounds of which are caught each year along the Atlantic Coast and Gulf of Mexico. The herring fisheries of the North Sea have yielded enormous quantities for more than a thousand years and still yield more than two billion annually.

Fish are utilized principally as food for man. Statistics indicating the value of the annual catch are presented in Chapter 12. In addition to being eaten fresh they are preserved by freezing, canning, salting, pickling, smoking, and even fermenting. Nonedible fish are made into oil, fertilizer, and meal. Fish and fish liver oils find many commercial applications. Hydrogenated or hardened fish oil is largely used for soap manufacture. The swim bladders of certain fish are made into isinglass. Cod, cusk, hake, pollock, and haddock skins and waste are utilized for glue manufacture. The skins of shark and a few other fish are tanned into excellent leather. Herring, shad, alewife and the scales of other fishes are used in pearl essence manufacture.

Shellfish. Shellfish are utilized to an extent scarcely appreciated by many people. In the United States the annual product of these fisheries constitutes approximately one-third of the total value of all the fisheries. The oyster industry yields, in addition to about $26,000,000 worth of a nutritious food product, several million dollars' worth of poultry grit, lime, and fertilizer. The fresh-water mussel industries produce pearl buttons and other useful ornaments valued at over $8,000,000. Our clam, scallop, and abalone fisheries are also fair sized industries. There appears to be an unfounded prejudice against the edible qualities of sea mussels. An industry greater than that of the oyster fishery might be developed if Americans, like Europeans, would eat this shellfish.

The annual production of the world's pearl and pearl shell industries exceeds $100,000,000. The Australian fisheries are of particular importance. Pearls have great value, a single strand occasionally bringing half a million dollars.

Crustacea. Lobsters, crabs, and shrimp are now widely esteemed as edible. Eighty years ago the blue crab was almost unknown as an article of food. Its rise to importance has been rapid, over 100 million pounds now being taken annually. Lobsters have been so much in demand that their numbers have seriously diminished. The Atlantic Coast of Canada remains the only large producer. Within the last decade frozen shrimp has become very popular in the United States, resulting in a sudden expansion of this fishery.

Seal Fur and Leather. The demand for beautiful fur encouraged the pelagic sealers to search every known rookery for these valuable aquatic mammals, until they were nearly exterminated. In 1912 an international agreement between Japan, Great Britain, Russia, and the United States ended pelagic sealing and

saved the fur seal. Now the United States has an annual revenue of over a million dollars a year from the Pribilof Island rookeries (Chapter 34).

Hair seals and walrus furnish hides from which valuable leathers are prepared.

Whale Oil and Meal. Whaling played a very important part in the early economic history of the United States. The New England whalers searched the oceans for whales and furnished a large part of the world with illuminating oil, candles, and whalebone. With the discovery of petroleum the importance of deep-sea whaling rapidly diminished. However, the invention of the harpoon-gun in 1874 gave the industry new life and the discovery about a decade ago of a practical means of hardening the oil by hydrogenation made possible the annual preparation of $70,000,000 worth of whale products.

Porpoises, dolphins, and blackfish furnish valuable oil and leather; but, as relatively few are captured in any one locality, the fishery is of little commercial importance.

Tortoise Shell. Turtle fisheries are established in nearly all tropical waters. Valuable meat is obtained from the green turtle and an ornamental material, tortoise shell, is procured from the shields of the carapace of the hawksbill turtle (Chapter 31).

Sponges. Sponge fisheries are of importance at Key West, Nassau, Algeria, and in the Mediterranean (Chapter 35). The limited extent of the fishery, together with the great demand for sponges, keeps the price high. Since sponges can be cultivated, more interest should be given to the fishery so that an industry of great commercial value might be developed.

Coral. The Japanese and Italian coral fisheries have furnished a valuable ornamental material for many centuries. Formerly, the Mediterranean Sea yielded the major portion of the world's production, but now Japanese coral is of major commercial importance (Chapter 9).

Salt and By-products. The ocean is a great potential source of common salt, potassium, magnesium and calcium salts, iodine, and bromine. At present, common salt is the most important inorganic product obtained by the evaporation of sea water; this industry is described in Chapter 2. While salt is usually a cheap product, its manufacture is essential for human life.

In hot arid countries where large tracts of level land lie close to the sea salt is usually made on a large scale. In certain districts of Portugal, Spain, France, China, and California there are valuable salines. Valuable by-products, such as potassium and magnesium salts and iodine, may be prepared from the mother liquors remaining after the crystallization of the salt. As yet, the industries have been slow to utilize these salts. In California, magnesia, magnesium salts, and magnesium oxychloride cement are manufactured in large quantities from the bittern (Chapter 3).

Vegetable Products. Seaweeds are more extensively utilized in Japan than in any other country. If they were harvested in similar quantities in other parts of the world, their annual production would reach a very high figure indeed. In addition to being almost universally eaten algae find numerous other uses in Japan. An important glue, or size, *funori,* is manufactured from certain species. Agar, or *kanten,* is prepared on a large scale. This substance, as well as being a food, finds extensive use as a medicine and in the preparation of media for bacterial growth.

In recent years the manufacture of seaweed extracts, especially algin and alginates and Irish moss extract, has become an important industry (Chapters 5 and 6) as many important new uses both in food and other industries have been found for these products; Agar is also being extensively manufactured in the United States.

In comparison with the tremendous quantity of marine vegetatation existent its present uses seem infinitesimal. Its chief purpose seems to be a source of nutriment for the thousands of forms of marine animal life.

Possibilities

As there are no longer any new lands or oceans to be discovered to take care of the expanding world population, the production of the existing lands and oceans will have to be increased. At present, certain areas are overfished, while others are neglected. Overfishing particularly threatens the aquatic animals, such as crabs, lobsters, and mollusks, which remain close to shore.

Hundreds of species of fish which occur in large quantities are seldom utilized. On the other hand, dogfish and sharks and other such fish should be eliminated because they destroy the food fishes. The number of food fish could also be increased by more extensive fish cultural operations.

Thus, while the ocean is likely to remain an unconquered wilderness, further knowledge of its animal and vegetable life would benefit man.

REFERENCES

Ahmad, B., "Observations on a Diatom (*Nitzschia closterium* W. SM.) as a Source of Vitamin A," *Biochem. J.*, **24**, 860–865 (1930).

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

Anon., "Yearbook of Fishery Statistics," Food and Agr. Organization United Nations, New York, Columbia Univ. Press, 1947.

Bigelow, H. B., "Oceanography, Its Scope, Problems and Economic Importance," Washington, Nat'l. Acad. Sci., 1931.

Bond, R. M., "A Contribution to the Study of the Natural Food-Cycle in Aquatic Environments," Bingham Oceanographic Coll., *Peabody Museum Bull.*, **4**, Art. 4 (1933).

Chapman, W. M., "The Wealth of the Ocean," *Scientific Monthly*, **64**, 192–197 (1947).

Clarke, F. W., "The Data of Geochemistry," *U. S. Geol. Survey Bull.*, **770**, 5th ed. (1924).

Clowes, A. J., "Phosphate and Silicate in the Southern Oceans," *Discovery Repts.*, **19**, 1–120 (1938).

Dakin, W. J., "The Aquatic Animal and Its Environment," *Linnean Soc. New South Wales Proc.*, **60**, Pts. 1, 2, 8–332 (1935).

Davis, W. M., "The Oceans," *Natural History*, **24**, 554–565 (1924).

Dittmar, W., "Report on Researches into the Composition of Ocean Water, Collected by H. M. S. Challenger," *Challenger Repts., Physics and Chem.*, **1**, 1–251 (1884).

Fiedler, R. H., "Fishery Statistics of the United States 1941," U. S. Fish and Wildlife Service, *Statistical Digest*, **7** (1945).

Fleming, R. H., "The Composition of Plankton and Units for Reporting Populations and Production," *Sixth Pacific Sci. Congress Calif. Proc.*, **3**, 535–540 (1940).

Haber, F., "Gold in Sea Water," *Z. angew. Chem.*, **40**, 303–314 (1927).

Johnstone, J., "An Introduction to Oceanography," Liverpool Univ. Press, 1928.

Joly, J., "An Estimate of the Geological Age of the Earth," *Trans. Roy. Dublin Soc.*, **7** (2nd ser.), 23–66 (1899).

Joly, J., "On the Geological Age of the Earth," *Rept. Brit. Assoc. Adv. Sci.,* 369–379 (1900).

Joly, J., "Radioactivity and Geology," London, A. Constable & Co., 1909.

Kahn, R. A., "Some Aspects of the Future Consumption of Fresh and Frozen Fishery Products," *Fishing Gazette,* **65,** No. 12 (Annual Review), 94–96, 142 (1948).

Lambert, W. D., "The Figure of the Earth and the International Ellipsoid of Reference," *Science,* **63,** 242–248 (1926).

Liversidge, A., "On the Amount of Gold and Silver in Sea Water," *Proc. Roy. Soc. N. S. Wales,* **29,** 335–349 (1895).

Lyman, J., and Fleming, R. H., "Composition of Sea Water," *J. Marine Research,* **3,** 134–146 (1940).

Makin, C. J. S., "On the Composition of the Atlantic Ocean," *Chem. News,* **77,** 155–157, 171–172 (1898).

McIntosh, W. C., "The Resources of the Sea," 2nd ed., London, Cambridge Univ. Press, 1921.

Münster, C. A., "On the Possibility of Extracting the Precious Metals from Sea Water," *J. Soc. Chem. Ind.,* **11,** 351 (1892).

Natterer, K., "Report of the Commission for the Study of the Eastern Mediterranean. Chemical Studies in Eastern Mediterranean. 1. Voyage S. M. 'Pola' in 1890" *Monatsh.,* **13,** 873–896 (1892); "2. Voyage S. M. 'Pola' in 1891," *Ibid.,* **13,** 897–915 (1892); "3. Voyage S. M. 'Pola' in 1892," *Ibid.,* **14,** 624–684 (1893); "4. Voyage S. M. 'Pola' in 1893," *Ibid.,* **15,** 530–604 (1894).

Russell, F. S., and Yonge, C. M., "The Seas," New York, Fred. Warne and Co., 1928.

Savage, R. E., "The Relation between the Feeding of Herring off the East Coast of England and the Plankton of the Surrounding Waters," Great Britain Ministry Agriculture and Fisheries, *Fisheries Investigations Series* 2, **12,** No. 3 (1931).

Schmelck, L., "Chemistry," *In Den Norske Nordhavs-Expedition, 1876–1878* Pts. 9, 1, Christiania, Grøndahl & Sons (1882).

Sonstadt, E., "On the Presence of Gold in Sea-Water," *Chem. News,* **26,** 159–161 (1872).

Sverdrup, H. V., Johnson, M. W., and Fleming, R. H., "The Oceans: Their Physics, Chemistry and General Biology," New York, Prentice-Hall Inc., 1946.

Taylor, H. F., "Resources of the Ocean," *J. Franklin Inst.,* **214,** 167–196 (1932).

Tressler, D. K., "The Wealth of the Sea," New York, Appleton-Century-Crofts Inc., 1927.

Vaughan, T. W., "International Aspects of Oceanography," Nat'l Acad. Washington, Sci., 1937.

Wheeler, A. S., "Composition of Sea Waters near Beaufort, North Carolina," *J. Am Chem. Soc.,* **32,** 646–649 (1910).

CHAPTER 2

Salt from Sea Water

Common salt is one of the necessary components of man's diet. Consequently, its manufacture has been of great importance since prehistoric days. Large quantities of salt are needed for human and animal food, and, in addition enormous quantities are used by the chemical and other industries.

The oldest method of making salt is by the evaporation of sea water, salt lakes, or inland seas. Enormous quantities of salt are obtained from underground deposits; much is also indirectly derived from such deposits by the evaporation of brines obtained from salt wells and springs. Many salt wells are made to yield great quantities of brine by pumping fresh water down into these deposits and drawing the brine out after the water has dissolved the salt. The original source of salt is the ocean. All the large deposits in the earth's crust resulted from solar evaporation of inland seas or "arms" cut off from the ocean.

The Importance, Properties and Uses of Salt

As long as man's diet consisted of uncooked food, the fresh meat that he consumed provided sufficient salt; but, when he began to boil his food, a considerable proportion of the salt was removed. This deficiency had to be compensated for in some way. It is not known how long ago man first began using salt from the ocean, but the Chinese obtained it before 1000 B.C. by evaporating sea water. However, the production of salt from sea water by solar evaporation is a comparatively modern practice.

In medieval times the production of solar sea salt was very crude, with little effort made to eliminate impurities. The sea water was run through long trenches into a series of shallow basins. After the sun and wind had effected a preliminary evaporation, the water was run into a second series of basins. After considerable concentration had occurred, the brine was run into a third series of shallow basins where it was allowed to remain until crystallization was complete. The salt was then raked into piles and removed for use.

The world's annual production of salt now exceeds 35 million metric tons and is increasing with the expansion of the chemical industries. The United States alone produces about 15 million metric tons (Table 5). At one time most of the commercial salt was produced either by the mining of rock salt or by the evaporation of brine produced by dissolving rock salt in situ. Nevertheless, the manufacture of solar salt from sea water is still an important industry in many countries. The amount of salt which could be obtained from the ocean is tremendous. The average salt content of a gallon of sea water is about 0.2547 pound. Since the average density of rock salt is 2.24 times that of water, the evaporation of the entire ocean, which has a volume of 331,000,000 cubic miles,

would yield approximately 4,500,000 cubic miles of salt! In comparison with these figures the output of the rock salt beds at Stassfurt, Germany and in Ohio. Michigan, New York, and Kansas appears trivial.

Common salt is more or less impure sodium chloride ($NaCl$), composed of 39.39 per cent sodium and 60.61 per cent chlorine. It is a white, lustrous solid which generally crystallizes into cubes. In solution with water it has a bitter, brackish taste and is neutral to indicators. Pure sodium chloride is slightly hygroscopic, taking up about one-half per cent of the moisture from the air at ordinary room temperature. It melts at 1421° F (772° C) and vaporizes rapidly at white heat. A saturated aqueous sodium chloride solution crystallizes as the hydrate, $NaCl.2H_2O$, from 19.4° F(−7° C) to −7.6° F(−22° C), and $NaCl.10H_2O$ separates at −9.4° F (−23° C).

TABLE 4. SOLUBILITY OF SODIUM CHLORIDE IN 100 PARTS BY WEIGHT OF WATER.

Temperature F	C	Sodium Chloride
5.0	− 15°	32.73
14.0	− 10	33.49
23.0	− 5	34.22
32.0	0	35.52
48.2	9	35.74
57.2	14	35.87
77.0	25	36.13
104.0	40	36.64
122.0	50	36.98
140.0	60	37.25
158.0	70	37.98
176.0	80	38.22
194.0	90	38.87
212.0	100	39.61
229.5	109.7	40.35

Concentrated solutions of sodium chloride possess antiseptic properties because it extracts water; therefore, salt is often used in the preservation of meat, fish, and other food products. As well as for seasoning food and preserving it, salt is used in large quantities for the curing of hides, the making of brines for use in refrigeration and ice factories, the making of dyes, and the preparation of sodium and chlorine. Commercially, common salt is the chief source of sodium of all sodium compounds, except sodium nitrate which is found in Chile. Large quantities of salt are used for making soda ash and caustic soda. Metallic sodium is prepared by the electrolysis of molten sodium chloride, chlorine being obtained simultaneously. From salt is prepared practically all commercial chlorine, a few compounds of which are: sodium hypochlorite, sodium chlorate, sodium perchlorate, bleaching powder, hydrochloric acid, and silver chloride. Industries which use large quantities of salt are: oil refining, hard soap, ceramic, various metallurgical, paper works, and textile.

In Table 5 on page 14 are presented data collected by the United States Bureau of Mines, indicating the quantities of salt sold or used for various purposes by producers in the United States in 1947 and 1948. It is evident from these figures that the food and feed industries use more evaporated salt than any

other industries. The chemical industries use salt principally in the form of brine (in solution without evaporation).

TABLE 5. SALT SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1947 AND 1948. INDICATED BY CLASSES AND USES IN SHORT TONS.*

Use	1947			1948		
	Evaporated	Rock	Brine	Evaporated	Rock	Brine
Chlorine, bleaches, chlorates, etc.	368,430	711,439	1,661,943	336,180	705,315	1,796,533
Soda ash	[a]	—	7,382,646 [d]	[a]	—	7,392,248
Dyes and organic chemicals	59,683	67,100	—	78,873	104,401	—
Soap (precipitant)	43,445	16,733	—	33,350	10,852	—
Other chemicals	96,958	510,747	[b]	91,529	523,737	[b]
Textile processing	33,518	117,724	—	22,838	92,555	—
Hides and leather	95,438	155,370	—	79,964	150,647	—
Meat packing	368,670	408,019	—	324,041	366,259	—
Fish curing	40,267	22,726	—	15,351	19,997	—
Butter, cheese, and other dairy products	108,323	5,236	—	97,339	5,017	—
Canning and preserving	150,482	16,694	—	125,958	18,853	—
Other food processing	231,408	24,271	—	193,896	19,279	—
Refrigeration	40,740	196,242	—	20,540	196,087	—
Livestock	528,481	205,375	—	553,966	238,532	—
Highways, railroads, dust and ice control	6,942	466,762	—	8,260	460,674	—
Table and other household	478,647	173,411	—	499,339	173,648	—
Water treatment	220,330	231,812	[b]	193,861	253,095	[b]
Agriculture	14,785	9,198	—	13,609	19,867	—
Metallurgy	22,094	65,027	—	16,625	49,152	—
Undistributed [c]	250,087	350,467	96,222	501,884	438,879	160,263
Total	3,158,718	3,754,353	9,140,811 [d]	3,207,403	3,846,846	9,349,044

[a] Data for evaporated salt, included with "Undistributed".
[b] Data for salt in brine, included with "Undistributed".
[c] Comprises miscellaneous uses and data not presentable by classes including most exports.
[d] Revised figure.

Market Grades and Specifications

Evaporated salt and rock salt are the two principal types of salt on the market. Evaporated salt, which is the highest grade, is of three kinds, according to the method of manufacture: granulated, made by the vacuum pan process; medium

* Harris, F. E., and Tucker, E. M., "Salt Output in 1948 almost 16½ Million Tons," Mineral Market Report, *U. S. Bureau of Mines, Minerals Yearbook,* **1739** (1949).

TABLE 6. ANALYSES OF SAMPLES OF SEA SALT.*
(Per cent on moisture-free basis)

	Domestic Salt	Imported Salts				
					Bahama Islands	
	California Leslie bulk salt from barrels, Leslie Salt Refining Co.	France: Bonaire Salt Exp. Co.	Spain: Pela Emprexado Navagacoa, Lisbon	Spain: Iviza	D. F. & H. F. Harriott, Turks Island	Alfred Slotts Estate, Turks Island
Radicals	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Tetraborate (B_4O_7)	None	?	Trace		None	Trace
Sulphate (SO_4)	0.021	1.692	1.727	1.03	1.72	0.403
Bicarbonate (HCO_3)	....	....	.013		....	....
Chloride (Cl)	60.70	58.51	59.34	59.36	59.44	60.16
Calcium (Ca)	.025	.764	.471	.44	.45	.167
Strontium (Sr)	....	....	.008	....	....	....
Magnesium (Mg)	.000	.090	.396	.22	.47	.022
Sodium (Na, calculated)	39.34	37.71	38.02	38.50	37.97	38.98
Silica (SiO_2), etc.	.008	1.312	.086	.30	.13	.293
Total	100.09	100.08	100.06	99.85	100.18	100.03
Sodium chloride (NaCl)	100.01	95.86	96.63	97.86	96.52	99.09
Moisture	.159	1.39	4.475	.65	4.19	.31
Remarks	Fine crystals	Coarse crystals	Coarse crystals	Coarse crystals	Coarse crystals	Large crystalline lumps

or flake, made in grainers or open pans; and solar, refined and sold as granulated. As a rule, the faster the brine is evaporated, the finer the size of the salt obtained. Vacuum pans and the Alsberger process consequently make the finest and solar evaporation the coarsest. Grainer salt is the intermediate size.

The granulated, or vacuum grade, comprises the chief portion of table salt marketed and some of the high grade industrial salt for food preparation. The latter is used, among other things, for canning, dairying, and baking (cake and biscuit mixes, etc.). Table salt, according to the United States Food, Drug and Cosmetic Administration, is fine-grained crystalline salt, containing, on a water-free basis, a maximum of 1.4 per cent calcium sulfate, 0.5 per cent (max.) calcium and magnesium chlorides, and 0.1 per cent (max.) insoluble matter.

Grainer salt is also used for canning and dairying where the flaky type of salt is desired. It is usually preferred for crackers, pretzels, and sauerkraut.

* Tressler, D. K., "Some Considerations Concerning the Salting of Fish," *U. S. Bureau of Fisheries, Doc.,* 884 (1920)., and Tressler, D. K., and Murray, W. T., "How Brining with Pure Salt Improves Fillets," *Fishing Gazette,* 49, No. 2, 24–26 (1932).

There are several grades of solar salt. The crude grade is commonly used for salting fish and curing meat. This grade and the next, which is ground and sized, are used for such industrial purposes as softening water, manufacturing chemicals, freezing ice cream, curing hides, etc. Refined salt, which is about one-third of the total amount, is made by dissolving and refining solar salt (Chapter 3). Then it is sold for table and household use and food preparation, etc.

Solar Salt

Importance and Location of Industry. Although the mining of rock salt and the production of salt by the evaporation of brine with artificial heat now greatly exceeds production by solar evaporation, the manufacture of salt from sea water by this latter process is still an important industry in many warm countries where the annual rainfall is light. In California a large proportion of the salt produced is from the solar evaporation of sea water. This state ranked sixth among the salt-producing states in 1948, producing 914,000 tons of salt by all methods. In 1948 a total of 746,303 tons of solar salt was produced in the United States. In Italy the solar sea salt industry is the major salt industry of the country. Spain exports large quantities of sea salt and Portugal has salt works at Aveiro, Figueria, Alcacer do Sal, and Setubal. There are "salzgarten" at various places on the Adriatic Sea, including Sabbioncello, Trieste, Pirano, and Copo d'Istra. France, Egypt, China, Japan, India, Brazil, and many of the islands of the West Indies also possess important solar sea salt industries.

The manufacture of salt from sea water can successfully compete with the production of salt from rock salt only when the industry is located where a cheap source of heat is available; about 90 per cent of the sea water must be evaporated before any crystallization can take place. Solar heat is the only important method of manufacturing salt from sea water; consequently, the product is called solar salt. In some localities solar sea salt is called bay salt to distinguish it from solar, artificial brine salt, which is also called solar salt. Inasmuch as rapid evaporation of the water is necessary, the solar sea salt industry has thrived only along the seacoast of countries having a dry climate or hot summers.

Moreover, in order to establish a successful salt works a large acreage of level land adjoining a bay or the ocean is required. The ground underlying the site must be nearly impervious to water. Soils which are most satisfactory are clays and marls. If the ground is "leaky", it must be puddled with clay before it can be used. This is very important, as leaks in the bottom of salt ponds are very difficult to stop and cause unnecessary dilution of the brine which reduces the yield of salt.

It is impractical, for obvious reasons, to discuss in a work of this nature all the commercial methods of salt manufacture from sea water. There are five chief types of processes in commercial use today: (1) The oriental leaching process. (2) The oriental solar process, in which no attempt is made to separate impurities from the salt. (3) The improved oriental solar process, in which sediment, calcium carbonate, iron oxide, and calcium sulphate are separated by preliminary evaporation of the sea water in concentration ponds. (4) The European solar process, in which the sediment, iron sulfide, calcium carbonate, and calcium sulfate are separated from the brine by preliminary evaporation of the sea water and the greater proportion of the chlorides of calcium and magnesium are removed

by withdrawing the mother liquor from the crystallizing ponds when these salts begin to separate. (5) The Norwegian process, in which sea water is concentrated by freezing and salt is recovered by the evaporation of the concentrated brine.

In addition to the sea salt made by the five types of processes mentioned above, a small amount is made in isolated places by the simple evaporation of sea water in pans by means of artificial heat. Some salt is obtained annually from the evaporation of sea water in natural lagoons which occur on some of the islands of the West Indies and in Mexico, China, and elsewhere.

In the oriental leaching process and oriental solar process no attempt is made to separate the sodium chloride from the other salts; consequently, these salts contain relatively large amounts of calcium, magnesium, and iron and are usually dark in color. The salt prepared by the improved oriental process usually contains less clay, calcium carbonate and sulfate, and iron oxide than that produced by the ancient oriental process since these substances are removed in the concentration ponds where the brine undergoes a preliminary concentration previous to its transfer to the crystallizing ponds.

Since the European salt trade demands a white salt, more pains are taken to separate the sand and clay from the salt. Moreover, the European salt-makers attempt to separate the calcium and magnesium salts by preliminary evaporation to a density of about 25° Bé. (1.196 sp. gr.) before the brine is run into crystallizing ponds, and by removing the bittern or mother liquor when it begins to separate salts other than sodium chloride. The European solar salt, however, is "wet" because the separation of the calcium and magnesium chlorides is imperfect and these salts impart hygroscopic properties.

The process of manufacturing salt employed in California is a modification of the European solar process. The California salt producers, having learned that dry salt brings a higher price in America than wet salt, are careful to see that their salt contains only traces of calcium and magnesium chlorides and sulfates. This is accomplished by drawing off the bittern at a relatively low density. Although they obtain a slightly smaller yield of salt, they produce nearly pure sodium chloride. Table 6 gives analyses of solar sea salts manufactured in various parts of the world.

The various processes for the manufacture of salt are described in the following. Since the California processes produce the purest salt and represent the best commercial practice, these methods will be considered in greater detail than the others.

The Oriental Leaching Method. According to this ancient process, which is still used by many Filipinos, level areas of land close to the sea are cleared of vegetation, the soil loosened and sprinkled four times daily with sea water from canals which run through the salines. After about five days, during which a quantity of salt has accumulated on the surface, the loose earth, together with the salt, is scraped into leaching vats where it is leached with sea water until most of the salt has been extracted and a brine containing 10 per cent or more of salt is obtained. Then by means of bamboo piping the brine is drawn off through a dike into a shallow cement, earthenware, or clay-lined well from which it is run into crystallizing ponds floored with smooth broken pottery set in mortar to retard seepage and prevent admixture of sand with the salt. When the brine has evapo-

rated sufficiently to deposit salt, the crystals are raked into piles every day after sundown and then gathered into baskets to drain.

The Oriental Solar Process. In China the simplest possible process of manufacturing solar salt is employed. Although there is no record to show just when the salines were established, the identical methods are known to have been in use for a thousand years or more. The salt is made by the solar evaporation of sea water without any attempt at the separation of the impurities from the sodium chloride. The process is essentially as described in the following:

Sea water is pumped into large evaporating basins by means of windmills. These basins, resembling innumerable tennis courts of great size, are constructed on the flats along the seacoast by leveling the ground and rolling it hard with a stone roller. They are separated from each other by low ridges of mud about 8 inches high and are arranged in groups so that they may be filled with a central pump. About 3 inches of sea water are pumped into the basins and allowed to evaporate, leaving a coating of salt on the bottom by the end of a week. This salt is scraped into a pile and shoveled into small boats. The bottom of the basins is then rolled again, more sea water pumped in, and the salt making continued. The basins are connected by means of small canals to the main salt yards which are either near a railroad or a river. The salt is stored at the salt yards in great heaps which are usually covered with mats.

The Improved Oriental Process. In some sections of China, Japan, and the Philippines solar sea salt is produced by a process resembling the European inasmuch as the sea water is first allowed to settle and concentrate in ponds until it is nearly saturated, and is then run into crystallizing ponds where the salt crystallizes from the brine. The preliminary evaporation which takes place in the crystallizing ponds permits the sediment to settle and also causes the precipitation of iron sulfide, calcium carbonate, and most of the calcium sulfate. Since the concentrated brine is allowed to evaporate to complete dryness, the salt produced is high in calcium and magnesium chlorides.

The European Solar Salt Process. The greater proportion of the world's production of sea salt is manufactured by the European solar process. Practically all the sea salt produced in Europe, the West Indies, South America and Africa is made in this manner. This process is a decided improvement on the ancient oriental solar process as the product contains less impurities. The chief countries of Europe which produce solar sea salt are France, Spain, Portugal, and Italy. The customary procedure followed in manufacturing salt by this method will now be described.

The salines or salt farms are laid out on low-lying flat land adjoining a bay or the ocean. The flats are enclosed by high dykes to prevent flooding from high sea or storms. Each "salt meadow" is subdivided by internal walls into compartments of different levels. One end of the salt farm is usually slightly higher than the other so that the brine may flow from one compartment to the other. When the dry season begins, sea water is either pumped or admitted through a canal at high tide into the higher compartment and allowed to stand in the concentration pond until the clay and other suspended matter settle. A preliminary evaporation takes place during the clarification. The concentrated, clarified sea water is then run out into shallow reservoirs where it remains until it reaches 23–25° Bé. (1.178–1.196 sp. gr.). By the time the brine has reached this density, the iron

sulfide and calcium carbonate have precipitated out and most of the calcium sulfate been thrown down. Then the nearly saturated brine passes into a second series of shallow reservoirs. The rate of flow of the brine is regulated so that by the time it reaches the last row of these compartments, salt has begun to crystallize; the brine is then at a concentration of 25.2° Bé. (1.2104 sp. gr.). The evaporation in reservoirs is allowed to proceed until the brine reaches a concentration of about 27° Bé. (1.229 sp. gr.). The saturated brine is then run through the canal into the crystallizing ponds where the salt crystallizes more or less rapidly, depending upon the rate of evaporation. The evaporation is usually continued until the mother liquor reaches a density of 32° Bé. (1.283 sp. gr.). If the crystallization is extended, salt containing large amounts of calcium and magnesium chlorides is obtained. The bittern is then run off into bittern ponds. In the Giraud district in France the mother liquors are worked up into magnesium and potassium salts, according to a process introduced by Balard which is described in the following chapter. After the bittern is run off, the salt remaining is broken up, raked together, and hauled to the salt yards where it is piled in large heaps in the open air to dry. Occasional showers purify it somewhat for the rain dissolves the more soluble calcium and magnesium chlorides.

Salt produced in this manner contains from 95 to 97 per cent sodium chloride. The impurities are chiefly due to calcium and magnesium chlorides and sulfates, as is shown by the analyses given in Table 6, on page 15. This salt is hygroscopic because of its high calcium and magnesium chloride content. It is highly prized for salting fish and hides. It is particularly desirable for salting hides when they are sold by weight because salted hides do not have a tendency to dry out and lose weight.

The California Solar Salt Industry. The solar sea salt industry has been particularly successful along the California coast because the rainfall during the salt-making season is very slight. The largest plants are located in Alameda and San Mateo counties near San Francisco. Three other plants are located in the southern part of the state. The general method of production is nearly the same in all these places although the various operations differ considerably in detail.

The salt-making process, as it is carried out in the plant of the Western Salt Company at the southern end of San Diego Bay, has been described by Palmer (1917) and Mason (1919) and is typical of California's industrial practice in the manufacture of high grade salt by solar evaporation. San Diego Bay, which is the source of supply of sea water, is a long and narrow "arm" of the Pacific Ocean. The inflow of fresh water is very slight, and consequently the salt content of the water at the southern end where the plant is situated is somewhat higher than that of sea water. According to Palmer samples of the water of San Diego Bay have occasionally run as high as 5 per cent sodium chloride. The net annual evaporation of San Diego Bay is 50 inches, a total evaporation of 60 inches against an average precipitation of 10 inches.

At high tide bay water is admitted through tide gates into four tide ponds which have a total area of 400 acres. The ponds are surrounded by a levee about 10.5 feet high and 4 miles long. The water is retained in the tide ponds for two weeks and then pumped into secondary ponds by means of two centrifugal pumps which have a combined capacity of 15,000 gallons per minute. Each pump has a 36-inch suction and a 24-inch discharge, the two discharge pipes uniting in one

36-inch line. By this means the water is lifted 8 feet to a sump. It then flows to the high point of the secondary ponds where it is distributed by means of gates between the ponds. This plant has nine secondary ponds, totaling 450 acres. By the time another flow of brine from the tide ponds is due (about two weeks) the water in the upper ponds has reached a density of about 6.77° Bé. (1.041 sp. gr.) and is run into the lower secondary ponds to make room for another run.

(Courtesy Leslie Salt Co.)

Fig. 2–1. Evaporation ponds on San Francisco Bay. Their size varies from 40 to 800 acres.

The lower secondary ponds are sometimes referred to as "lime ponds" as the calcium carbonate settles to the bottom at a brine density of about 7.82° Bé. (1.057 sp. gr.). The evaporation is continued in the lower secondary ponds until a density of 9.26° Bé. (1.0682 sp. gr.) is reached. The brine is then run to the pickling pond which has an area of 200 acres. In this pond the evaporation is continued until the brine has a density of 24.1° Bé. (1.193 sp. gr.). At 13.78° Bé. (1.095 sp. gr.) calcium sulfate begins to settle out and is almost entirely precipitated by the time the density reaches 1.193 sp. gr. At this point the brine is run into the crystallizing ponds of 100 acres where salt begins to crystallize at 25.2 Bé. (1.2104 sp. gr.).

The density of the brine in the crystallizing ponds is such that 1 inch of salt is thrown down for each 8 to 10 inches of annual evaporation of water; therefore, the annual deposit is from 5 to 7 inches. Since the weight of 1 acre inch of salt is approximately 110 tons, the "crop" is 550 to 770 tons per acre.

When the density of the brine in the ponds reaches 29.67° Bé. (1.2574 sp. gr.), the mother liquor is transferred to the bittern ponds. Sodium chloride will crystallize out in a nearly pure form except for a small percentage of magnesium chloride up to a density of 30° Bé. (1.2609 sp. gr.); but, above this density other salts are deposited, magnesium sulfate being the first to be precipitated.

"Harvesting" usually begins the latter part of August and continues until the

latter part of November. The crystallized salt is broken with a special plow and then gathered by a dragline into small two-way dump cars on 36-inch tracks. A small gasoline "locomotive" hauls the loaded cars out of the crystallizing pond and the salt is dumped into a V-shaped bin about 100 feet long, 4 feet wide, and 4 feet deep. Its sides are sloping and the bottom is provided with rack and pinion gates which are operated from above by hand wheels. In this manner the salt is discharged to a screw conveyor which works it to a belt elevator. This elevator dumps the salt into the "washer", a trough 2 feet wide, 4 feet deep, and 30 feet long with a screw conveyor in the bottom. The salt is washed by working it through the trough against a current of brine from the "pickling" pond (density about 12.5° Bé., 1.0944 sp. gr.). The brine flows back to the pond after passing through the trough.

The screw conveyor from the washer delivers the salt to a bucket elevator which lifts it about 50 feet. The salt receives a final brine washing at the bottom of the bucket elevator and passes under a spray of fresh water as it is elevated. This removes any dirt or mother liquor that may have escaped previous washings. According to Palmer, "the dried product analyses 99.823 per cent NaCl. The small amount of impurities which does remain consists of sulfates of calcium, magnesium, and sodium, and chlorides of calcium and magnesium." The bucket elevator dumps the salt into another trough, containing a screw conveyor which works it out on a trestle. Gates in the bottom of the trough permit its discharge at any desired point to large stock piles which are usually 50 feet high.

After the salt has dried to 1.5 to 2.0 per cent moisture, it is shipped in sacks or bulk as needed. Belt conveyors carry the salt from the stockpile to a permanent screening and loading plant. The salt is elevated by bucket elevator and screened into 3 sizes. It is then carried to 4 large bins of 100 tons capacity each and either sacked in various size bags from these bins or run on a belt directly into freight cars for shipment in bulk.

The annual output of the plant of the Western Salt Company, which has been described, is from 50,000 to 60,000 tons.

The salt-making operations of the plants around San Francisco Bay are conducted in a similar manner although differing in some details. As in the San Diego district the bay water is not taken into the works continuously, but only when the tides are highest. Evaporation proceeds more slowly, and, consequently, the annual yield per acre is somewhat less. The rainfall and evaporation in inches during the salt-making season at San Francisco Bay are given below:

Month	Rainfall (in.)	Evaporation (in.)
April	1.36	3.38
May	1.14	5.31
June	0.67	6.62
July	0.00	7.81
August	0.00	7.81
September	0.00	4.94
October	0.77	2.94

The salt content of San Francisco Bay is lower than that of San Diego Bay. Comparative statistics are given by Phalen in Table 7.

TABLE 7. DENSITY AND SALINITY OF SEA WATER USED IN SALT MAKING IN CALIFORNIA *

Source	Date of Collection 1912	Density °Bé.	Specific Gravity	Salt (as NaCl) (%)
San Francisco Bay at Mount Eden	Oct. 5	3.53	1.025	3.44
San Francisco Bay at Alvaredo	Oct. 8	3.12	1.022	3.34
San Diego Bay	Oct. 17	4.10	1.029	4.00
Sea water	....	....	1.027	3.72

All but three of the sea salt works of California are situated on San Francisco Bay because a large area of level marl lies in proximity to it. This permits the making of solar salt in ponds without danger of dilution through the leaks in the bottom of the ponds. The salt works in this vicinity cover 25,000 acres. The average annual yield of salt from an 1800-acre plant is 25,000 tons.

Procedure at San Francisco Bay. At high tide bay water is admitted through a gate into the main canal. Archimedean screws propelled by windmills, centrifugal pumps operated by gasoline engines, or electrically driven water wheels pump the water into settling ponds which are at least eighteen inches deep. Here the suspended matter settles to the bottom and preliminary evaporation takes place. In the first settling ponds silica, alumina, and iron sulfide precipitate out; in the secondary or lime ponds calcium carbonate and more iron sulfide come down. Walls built within the ponds make the brine circulate as it passes through the reservoirs. In the settling ponds a lively growth of green and brown algae, diatomaceae, and bacteria are found. Larvae of the marsh fly and other insects are numerous in these ponds; and in the ponds containing nearly saturated brine "brine-worms" (a small crustacean *Artemia salina*) are found in enormous numbers.

The brine passes from the settling ponds to the so-called pickling ponds in which most of the calcium sulfate separates in brown, green, or yellow crystalline concrements. In addition to calcium sulfate iron sulfide is found in the sediment of the pickling ponds; this sulfide is probably formed by the reduction of the sulfates by the organic matter. The brine remains in the pickling ponds until it reaches a specific gravity of 1.198 to 1.2085 (23.97° to 25.0° Bé.). By this time practically all the gypsum has been deposited. Even at 1.194 sp. gr. (23.45° Bé.) there is no danger of deposition of gypsum on the salt crystals in the crystallization ponds. However, due to the irregularities in the density of the brine, which varies at times even within the same pond, brine of lower density than 1.198 sp. gr. (23.97° Bé.) is never used in the crystallizing ponds.

As the concentration of the brine approaches saturation the brine-worms and algae die and the solution becomes pinkish in color due to the growth of certain red and pink bacteria. This change of color indicates that the brine is ready to be transferred to the crystallization ponds.

From the liming ponds the brine, or pickle as it is sometimes called, passes to the crystallization ponds where the salt begins to crystallize at a density of 1.2104 sp. gr. (25.16° Bé). When the ponds are filled to a depth of 10 or more inches, large salt crystals are usually obtained. However, the temperature of the brine and

* Phalen, W. C., "Technology of Salt Making in the United States," *U. S. Bureau of Mines Bull.*, **146** (1917).

the rate of evaporation also affect the size of the crystals. Cold weather causes the formation of small hard crystals. Hot weather and a low brine stratum during crystallization result in the formation of soft crystals.

As more and more of the salt crystallizes from the solution the magnesium and calcium chloride content of the mother liquor increases; this causes the mother

(*Courtesy Leslie Salt Co.*)

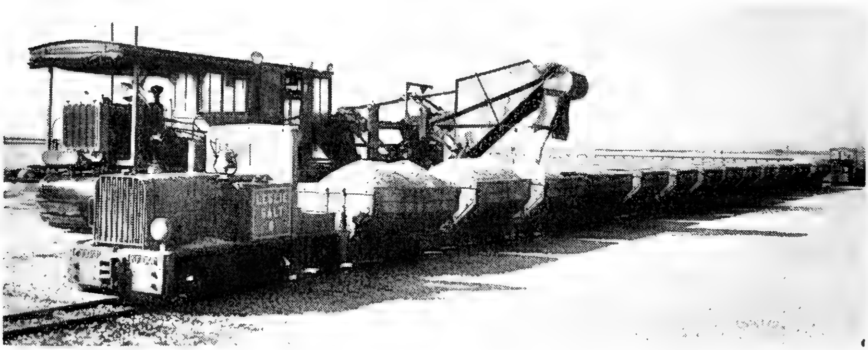
FIG. 2–2. In California, solar evaporation ponds are flooded by a system of canals. The system is so arranged that salt water can be diverted to any ponds requiring refilling to replace evaporation.

liquor to become oily in appearance. The greater proportion of the salt crystallizes from the solution between the densities 1.2185 sp. gr. (26° Bé.) and 1.2341 sp. gr. (27.5° Bé.).

It requires some skill to regulate the requirements of the crystallizing ponds so that there will always be enough saturated brine on hand from the last concentration ponds (pickling ponds). If there is an oversupply the mother liquor is drawn off at 1.2394 sp. gr. (28° Bé.). Otherwise, the brine is allowed to remain in the crystallization ponds until it reaches a density of 1.2500 sp. gr. (29° Bé.) as some salt continues to crystallize. If the brine is permitted to evaporate at higher densities, the salt which crystallizes becomes more and more impure and a film of salt begins to cover the greater part of the pond. The mother liquor which is drawn off from the crystallizers is called bittern. The salt manufacturers utilize the bittern for making various by-products; these processes are described in Chapter 4.

The crystallization ponds are filled from two to five times each season. The brine is run in on the previous crystallizations for the salt is not harvested until the end of the season. In this region the salt is removed from the crystallizers before the December rains begin.

In the smaller salines the salt is harvested with picks and shovels and is hauled to the piles in wheelbarrows. The larger and more modern plants use small dump cars, run on movable rails and hauled by gasoline locomotives, for transporting the salt to the washing machine. The removal or "lifting" of the salt with pick and shovel is quite efficient in one respect: it is possible to remove practically all of the salt from the beds without disturbing the bottom and thus contaminating the salt with earth. However, an efficient, mechanical lifter, or harvester (Fig. 2–3),



(Courtesy Leslie Salt Co.)

FIG. 2–3. Harvesting solar sea salt. Huge harvesting machines gather the salt during the brief harvesting period. As the tractor moves forward, a revolving cutter breaks up the solid bed of salt, 3 to 6 inches thick, and loads it into cars. Each harvester has a capacity of 125 tons per hour. The salt train moves on portable tracks which will be moved later to another pond. The harvesting of over a half million ton crop takes about 12 weeks.

(Courtesy Leslie Salt Co.)

FIG. 2–4. Crude solar sea salt by the train load is on its way to the large stock piles shown in the picture. The train passes through the building shown above where each car is automatically unloaded.

consisting of a horizontal scraper mounted on a large caterpillar truck, has been perfected. As the truck moves slowly along, the scraper takes up the salt and throws it on a conveyor which empties it into the dumping cars. This mechanical lifter can turn in any direction.

When the salt is removed from the beds, it is often dark-colored due to admixed iron sulfide, organic matter, etc.; occasionally it contains red, yellow, and brown streaks. However, these discolorations may be removed by careful washing.

The salt is next washed with brine, usually in large washing tanks. Revolving screws in the tanks keep it in a state of constant agitation, turning it over with a scouring action and drawing the salt up an incline to a point of discharge above the water line which permits drainage by gravity. The loosened particles of foreign materials float away with the overflowing brine. Lumps are broken up and the salt is sprayed with fresh water as it passes up a conveyor and on to a huge stockpile.

Some of the solar salt made in California is marketed in bulk without further treatment. Much is dried in a kiln, then crushed, screened, and sacked. Large quantities are refined by recrystallization, as will be described in the next chapter.

REFERENCES

Ablan, L., Montilla, J. R., and Martin, B. M., "Salt-Making Industry of Northern Luzon," *Phil. J. Sci.*, **72**, 319–328 (1940).

Anon., "Production and Distribution of Salt in the United States by Primary Producers," Washington, U. S. Tariff Commission, 1935.

Anon., "Salt," San Francisco, Leslie Salt Co.

Anon., "History of Salt," Chicago, Morton Salt Co., 1949.

Anon., "Leslie Salt Expansion," *Chem. and Eng. News*, **25**, 1516 (1947).

Anon., "Bay Area Salt Goes to Chlorine Plant," *Chem. and Met. Eng.*, **53**, No. 5, 198 (1946).

Anon., "Salt," *U. S. Bureau of Mines, Mineral Trade Notes*, **11**, No. 2 (1940).

Badger, W. L., and Baker, E. M., "Inorganic Chemical Technology," 2nd ed., New York, McGraw-Hill Book Co., 1941.

Bartlett, H. W., "Salt Yielded by Sea Water Evaporation Harvested by Huge Tractor," *Pit and Quarry*, **20**, No. 8, 22–26 (1930).

Bowles, O., "Non-metallic Minerals," *Mining and Met.*, **25**, 82–88 (1944).

Brighton, T. B., "Salt-Making on the Great Salt Lake," *J. Chem. Education*, **9**, 407–415 (1932).

Brighton, T. B., and Dice, C. M., "Increasing the Purity of Common Salt," *Ind. Eng. Chem.*, **23**, 336–339 (1931).

Buchen, J. C., "Evaporating Salt from World's Largest Mineral Deposit," *Mining Met.*, **18**, 335–338 (1937).

Cole, L. H., "The Salt Industry of Canada," Ottawa, Canadian Dept. Mines, 1930.

Hamm, W. S., "Purer Salt for the Philippines," *Philippine Institute of Science Spec. Bull.* (1949).

Harris, F. E., "Marketing of Salt," *U. S. Bureau of Mines, Information Circular*, **7062** (1939).

Harris, F. E., and Tucker, E. M., "Salt," U. S. Bureau of Mines, "Minerals Yearbook," 1031–1045, 1946.

Harris, F. E., and Tucker, E. M., "Salt Output in 1948 Almost 16½ Million Tons," *U. S. Bureau of Mines, Mineral Market Rept.*, **1739** (1949).

Hickok, K. E., "Non Metallic Minerals. VI. Salt," *Mines Mag.* (*Colo. School of Mines*), **30**, 642, 655, 660 (1940).

Hyler, J. E., "The Production of Salt," *J. Chem. Education*, **12**, 203–207 (1935).

Knott, E., "Solar Salt," *Pharm. J.*, **156,** 252 (1946).

Lee, J. A., "Refining the Salt of the Earth," *Chem. and Met. Eng.*, **42,** 124–128 (1935).

Manning, P. D. V., "Sodium Salts," *Mineral Ind.*, **49,** 557–568 (1940).

Mason, F. H., "Recovery of Salt from Sea Water," *Min. Sci. Press*, **118,** 528–530 (1919).

McDaniel, C. M., "Something about Solar Salt," *Canner*, **85,** No. 12, 14, 16 (1937).

McQuaid, J. C., "California Honors Salt from the Sea," *Morton's Spout*, **2,** No. 1, 4–8 (1947).

Palmer, L. A., "Salt Manufacture by Solar Evaporation of Salt Water," *Met. Chem. Eng.*, **16,** 317–319 (1917).

Pask, A. H., "Salt, Its Production, Uses," *Eng. J.*, **24,** 529–531 (1941).

Phalen, W. C., "Technology of Salt-Making in the United States," *U. S. Bureau of Mines Bull.*, **146** (1917).

Phalen, W. C., "Salt Resources of the United States," *U. S. Geol. Survey Bull.*, **669** (1919).

Phalen, W. C., "Marketing of Salt," *Eng. and Min. J.*, **115,** 185–190 (1923).

Phalen, W. C., "Salt, Industrial Minerals and Rocks," *Am. Inst. Min. and Met. Eng.*, 643–670 (1937).

CHAPTER 3

The Refining of Sea Salt

The Necessity of Refining Sea Salt

Regardless of the process used in making solar sea salt the crude product contains more or less insoluble mineral and organic matter, chiefly scraped up from the floor of the saline, an appreciable amount of calcium and magnesium chlorides, sulfates, and many microorganisms.

Sodium chloride has a brackish, but not bitter, taste, whereas, calcium and magnesium salts are very bitter. Consequently, the higher the content of calcium and magnesium salts in common salt, the more bitter its taste. Iron, organic matter, and bacteria, usually found in crude solar salt, cause it to be colored. Some sea salt contains relatively high numbers of red bacteria which often give it a pink tinge. Organic matter of marine origin give sea salts peculiar odors, often described as the "smell of the sea." Although pure sodium chloride is only very slightly hygroscopic, calcium and magnesium chlorides absorb moisture readily; therefore, the presence of even small amounts of these salts is sufficient to make sea salt hygroscopic.

For many purposes, such as table, dairy, and chemical, nearly pure salt is required. The demand for pure salt causes it to bring a higher price than crude salt. Since it is difficult to produce high grade salt by the solar process, the most modern salt works, desiring to market their salt in the most valuable form, refine the low grade salt by various processes, which will be considered in this chapter.

Little sea salt is refined in Europe since most of the refineries are located in Great Britain, Austria, and Germany, where the salt is obtained either from mines or wells.

The American sea-salt refining industry is located in the vicinity of San Francisco Bay, California, the center of the solar sea-salt industry. Four salt works operate very large refineries in that locality.

The composition of the solar sea salts from various parts of the world is given in Table 6 on page 15.

American Processes of Refining Sea Salt

Principles and Methods. Sea salt is refined either by rewashing, grinding, and screening the crude product, or by dissolving and recrystallizing it in grainers or vacuum pans.

A clear understanding of the mechanical principles of salt-crystal formation is necessary for a scientific study of salt refining. Salt crystals have their beginning as vapor rises from heated brine and tiny specks begin to appear at the surface. The individual "seed crystals" enlarge rapidly, the rate of growth depending upon the rate of heat supplied and subsequent evaporation. If undisturbed, the salt

particle enlarges to a small cube, its weight indenting the liquid surface. A transparent, four-sided, fence-like rib of crystal, caused by the evaporation from four sloping brine filaments, forms around the four top edges of the little cube and results in a tiny, delicate, dish-like structure of salt with the original cube at its bottom. The cube enlarges, becomes heavier, and finally settles slightly, although still prevented from sinking by surface tension.

A second fence-like crystalline rib forms in this newly depressed area and surrounds the first rib, thus enlarging the four-sided crystal dish. The processes of accumulating weight, settling slightly, and forming another addition to the rim of the dish are repeated until finally a most beautiful hopper-shaped structure appears on the surface. Taken from the liquid and dried on a piece of blotting paper, the hopper crystal, which may be, if carefully made, half an inch or more across and a quarter-inch deep, consists at the apex of a relatively large cubical crystal, with four outwardly flaring, delicately ribbed, thin shell-like flake walls. The corner "seams" are constructed of a number of smaller cubical pieces, arranged like the steps of an Egyptian pyramid.

The slower the evaporation the greater will be the proportion of "flake" to "cube" in any one hopper. When first formed, the hoppers are very thin and fragile; but, if allowed to remain undisturbed on the brine surface, the apex cube and the corner cubes, or steps, enlarge, and the fragile walls thicken until the hopper dips, fills with brine, and slowly sinks to the bottom.

Not all of the original salt crystals develop into perfectly formed individual hoppers. The new-formed particles exhibit strong affinity for each other and at every opportunity gravitate together, sometimes forming a thin, flat mat composed of little cubes and flakes. Several partly grown hoppers may unite at their edges to form multiple hoppers.

If evaporation is allowed to proceed still more slowly and the brine surface is not agitated, as in well-protected solar ponds or coarse salt grainers, the hoppers will grow much larger and thicker before sinking. After a large hopper sinks, it is filled with small hoppers and particles that have early lost their floating balance and gone to the bottom, and it eventually becomes a solid pyramid-shaped mass with a flat base. Under extremely slow evaporation, as by solar heat, there finally develops a bunch of beautifully formed, massive, block-like crystals with sharp edges and corners; this is a typical formation of crude solar salt.

If the evaporation is repeated with brine near the boiling point, the escaping water vapor sets up a local circulation in the liquid, agitating the surface and partly preventing hopper formation. Consequently, the new made salt particles sink while still in the small hopper stage, as either incomplete hoppers, single cubes, or groups or bunches of united cubes. If the brine is allowed to boil violently, as in a vacuum evaporator, hopper formation is prevented, resulting in a product containing no flakes and only small cubes. Therefore, we may draw the following conclusions: (a) Violent boiling or stirring always results in fine cubical particles of salt with no hoppers. (b) Near the boiling point evaporation with gentle stirring or local brine circulation produces a mixture of larger cubical particles and small, thin-walled hopper crystals. (c) Slow evaporation without agitation produces hopper crystals with a large proportion of thicker-walled "flake" grains. (d) Very slow solar evaporation produces solidified and filled hoppers and block-like cubes, but almost no fine cubes or thin-walled hoppers.

The shape, size, and physical characteristics of salt crystals are controlled in practice by the manipulation of the brine during crystallization and by the methods employed in draining, kiln-drying, and screening the crystallized product. Proper manipulation is accomplished by the control of the brine temperature during crystallization, by the amount of mechanical stirring or agitation of the brine, and

(*Courtesy Leslie Salt Co.*)

FIG. 3–1. Modern plant of the Leslie Salt Co. at Newark, California, where salt is produced by solar evaporation and then refined for domestic and industrial use.

by the length of time the newly formed crystals are allowed to remain in the brine after sinking and before removal.

The grains in the marketed product are only approximately the shape of those produced in evaporation experiments because the subsequent handling of the crystals in the refinery by centrifuging, storing in warehouse, steam-drying in rotary kilns, screening to size, etc., breaks the crystals and effectually changes their original appearance. Nevertheless, the nature of the final product, whether coarse grained or fine grained, flaky like filaments resembling mica or cubical like minute dice, depends upon how the brine is evaporated.

The brine in vacuum pans boils violently, and the salt thus produced consists of very small cubical crystals. The particles are smooth and slightly rounded at the corners and edges. When thoroughly dry and screened between certain size limits, vacuum-pan salt pours and sifts readily.

The so-called English flash grainer system operates by first raising the temperature of the brine considerably above its boiling point in a closed heater and by spurting the superheated brine into a drum, or chamber, where it separates

("flashes") into (a) steam that escapes from the upper part of the drum and (b) concentrated hot brine, filled with "seed" crystals, that escapes from the lower part of the drum into a mechanically raked grainer of large area. On the brine surface of the grainer the seed crystals rapidly form small, thin-walled hoppers, consisting of only a minimum proportion of apex cubes. Flash grainer salt is light and fluffy and in mass has a "soft" appearance due to the volume of thin-walled hoppers contained in it. When dried and screened the flash-grainer product, viewed under a magnifying glass, appears to consist largely of thin, splintered flakes which, of course, are the broken walls of the thin hoppers.

The composite-salt grainer system operates by discharging dust salt from refinery screens, or fine grained salt from a vacuum pan, into a steam-heated, mechanically raked grainer in which concentrated brine is being evaporated at moderate heat. This supercharging bunches the hopper crystals of the usual medium-temperature grainer and the fine particles of added salt into more bulky crystalline units, resembling relatively coarse standard grainer salt. More rapid evaporation produces a finer-grained aggregate. Composite salt has a ready market, and the method used converts the dust salt into a better marketable product, without the need of dissolving and re-evaporating it. The steam-grainer system is one of the most flexible and adaptable of all salt-making systems because it can make use of live steam to boil the brine and produce fine grained salt, or, at lower temperatures, to produce any of the flaky or hopper crystal formations. It requires less skilled labor than the vacuum system and can be operated at reduced capacity by shutting down one or more grainers when desired, whereas vacuum pans should operate only at full capacity. Mechanically raked grainers, equipped with surface splashers or agitators, permit the sinking of hopper crystals at any given stage of their growth. The finished product can be either quickly or slowly raked out so as to closely control its physical characteristics.

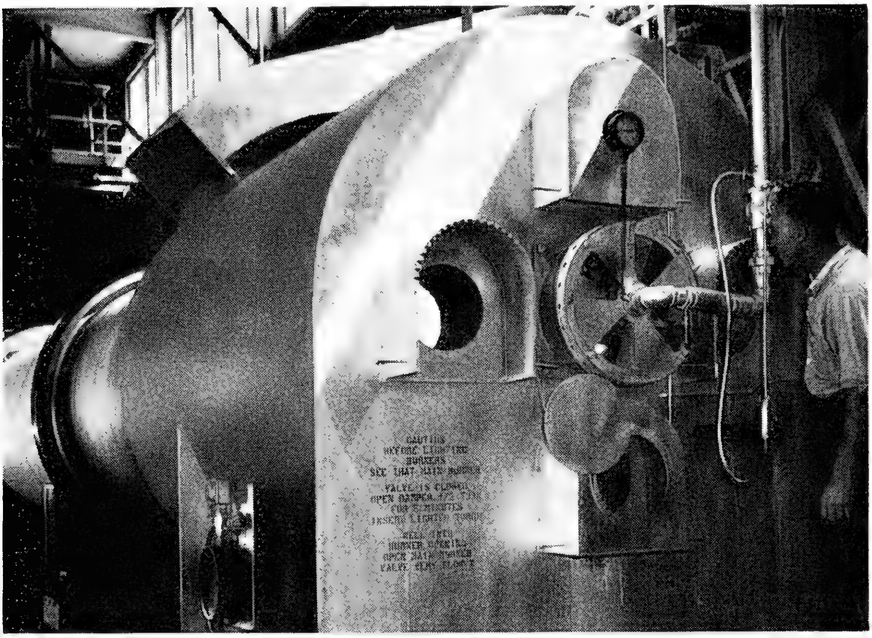
The direct-fired pan system is similar to the steam grainer. However, this system has practically been discarded throughout the United States due to the danger of the plates buckling by overheating when scale deposits on the hot surface and the consequent high cost of upkeep. In addition this system usually heats the brine unevenly, resulting in a badly mixed product.

Solar salts, evaporated from brine obtained from wells, and sea water are mostly coarse and heavy crystals, having the distinct characteristic shape of the original hopper. When cracked, crude solar salt breaks into somewhat cubical particles; finer grinding breaks it into jagged and sharp-edged grains. The smooth cubical crystal form of vacuum pan salt and the flaky characteristics of steam evaporated grainer salt are not present in the finely screened grades of solar salt.

Refining by Rewashing. Only the very best solar salts can be converted into high grade refined salts without recrystallization. Careful control of the ponds during the evaporation season is required to produce a salt of sufficiently high quality. Consequently, only a few salines on the California coast make pure enough solar salt to be refined by washing.

The washing process is usually carried out in a revolving screen, two-thirds submerged in an alkaline sodium chloride solution. After washing, the salt is screened to separate the coarse from the fine grains, the latter being sold as fish salt. The coarse salt, which is purer, is used for the preparation of higher-grade salt [i.e.,

table and dairy]. The wash-solution, obtained by dissolving high-grade salt in fresh water, removes a part of the magnesium salts and other impurities from the crude salt. A fine precipitate of magnesium hydroxide forms in the wash liquor. The solution runs out through an overflow pipe and is then returned to storage tanks where it becomes alkaline again. The alkalies which are used in the wash solution include lime and sodium carbonate and bicarbonate. Sometimes crude trona



(Courtesy Leslie Salt Co.)

FIG. 3–2. Rotary kiln used for drying refined sea salt. Powerful fans draw heated air through the salt as it is tumbled over and over.

from the alkali lakes of California is used. In most cases lime is sufficient; however, an excess of lime causes a fine white flocculent precipitate in the solution of the washed salt. In some plants the washed salt is crushed and washed again with a dilute solution of ultramarine in a centrifugal washer. This produces a white salt.

The washed salt must be dried before grinding as it contains from 1½ to 2½ per cent water. Ordinarily, this is accomplished by heating it in a revolving horizontal drier at a temperature of 190° to 210° F (87.8° to 98.9° C). At higher temperatures the salt becomes discolored (reddish-gray). The drier is usually a rotary cylinder which revolves slowly as the salt passes through it. It is provided with the steam pipes of a steam jacket, or other heating equipment, which heats the salt to the proper temperature. Hot air is pumped through the drier to facilitate evaporation of the moisture contained in the salt.

Various types of machines are used for the grinding of dried salt. Carr disintegrators and other grinders, equipped with beaters, are quite satisfactory although seldom used. Roller mills, having equal speed rollers, are commonly

used. Impurities of light weight are removed from the salt by air-suction over the screens in the screening machine.

Shaker salt is obtained by adding about 1 per cent fine magnesium carbonate. Some of the salt manufacturers in the eastern part of the United States use fine sodium carbonate in place of magnesium carbonate; but sodium carbonate develops an unpleasant odor when it is used with sea salt unless the latter has been recrystallized. To make the salt "free-running" 1½ per cent white air-floated talcum powder is sometimes added instead of magnesium carbonate.

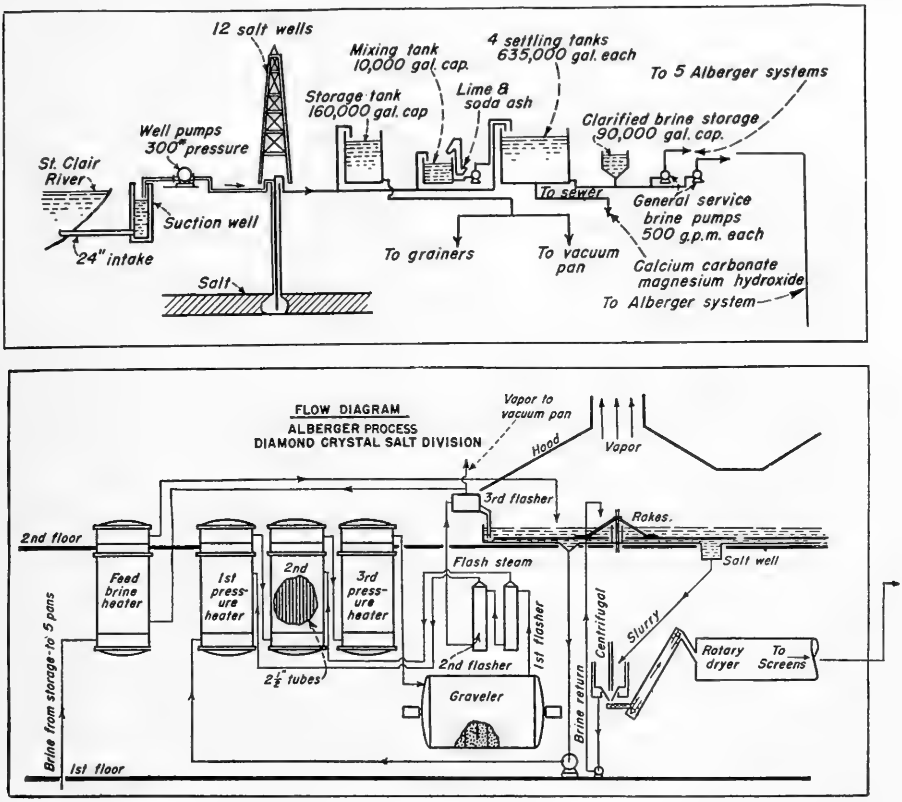
Refining by Recrystallization in Grainers. In some American sea salt factories the refining is carried out by recrystallizing the salt in grainers. The crude solar salt is dissolved in a tank containing fresh water until a nearly saturated solution is prepared. This brine is limed, settled, preheated, and then evaporated in the grainers while live or exhaust steam is passed through pipes immersed in it. A grainer consists essentially of a long, narrow, shallow vat built of wood or metal, supported on a framework, or of reinforced concrete, supported on a foundation of sand.

Crystallization begins as the little cubes which float on the surface are gradually submerged in the hot brine. During evaporation new crystals form a cup-shaped concrement on the sides of the original cube until it becomes heavy enough to sink to the bottom. A scraping conveyor carries the salt out of the grainer and deposits it on a platform where it is allowed to drain. Then it is usually dried in a revolving horizontal drier. After the salt is in solution a small amount of lime may be added to it before it leaves the dissolving tank. It is allowed to stand long enough for the precipitated impurities to settle and for a clear white salt to be produced. Prior to the evaporation in the grainer the brine is preheated and the gypsum precipitated.

The Alberger Salt Refining System. The Alberger process is a relatively new system of refining salt. At present it is not used in refining solar salt, but only in producing salt from brine obtained from salt wells. To produce salt by the Alberger process a preheater, three pressure heaters, two gravellers, three flash evaporators, and an open evaporating pan, shaped like a figure 8 (Fig. 3–3), are needed. Although the brine, which has been purified and clarified by treatment with lime and soda ash, followed by settling, is raised in temperature, it does not boil as it passes through the preheater and pressure heaters. In the third pressure heater the brine reaches 290° F (144.3° C), the temperature at which the optimum removal of calcium sulfate is effected. The brine, passing through the graveller where the calcium sulfate precipitates, is deposited on cobble stones.

The purified brine is now cooled by passing through a series of three flash evaporators. The critical crystallizing temperature 226° F (107.8° C) is reached in the third flasher, at which point about half of the salt crystals have crystallized into microscopic cubes. The crystal-seeded brine is ejected into the open evaporating pan where the surface evaporation of the rapidly cooling brine results in the formation of delicate, hopper-shaped, flake-like crystals. After they have settled, the crystals are drawn from the pan and whirled in a basket-type centrifuge to keep the brine from adhering. The drying is completed in a steam-heated, rotary, counterflow air-drier.

Recrystallization in Vacuum Pans. A number of factories on the Pacific Coast have adopted vacuum pans for recrystallization of the crude solar salt. Although



(*Courtesy Food Industries*)

Fig. 3–3. Flow diagram of Alberger salt refining system. The Alberger process employs a pre-heater, three pressure heaters, two gravellers, three flash evaporators and an open, figure-eight shaped evaporating pan. In the pressure heaters the brine increases in temperature and pressure but does not boil. In the third pressure heater, the brine reaches 290° F (143.3° C), the temperature at which optimum removal of calcium sulfate is effected. The brine is then passed through the gravellers where the calcium sulfate precipitates. The sulfate deposits on cobble stones placed in the unit for that purpose. The purified brine from the gravellers is now cooled in a series of three flashers. The critical crystallizing temperature is reached in the third flasher at 226° F (107.8° C). At this point, about half of the yield of salt crystallizes spontaneously as microscopic cubes. The crystal-seeded brine is ejected into the open evaporating pan, where surface evaporation of the rapidly cooling brine results in the formation of delicate, hopper-shaped, flake-like crystals. The settled crystals are drawn from the pan and separated from the adhering brine in a basket-type centrifuge, preceding the high temperature drying operation. The drying is completed in a steam-heated, rotary, counterflow air dryer, which reduces the moisture content of the salt to less than 0.1 per cent. Steam from the boilers at 210 psi pressure is used to heat air for the dryers, and the condensate is returned to the boiler.

the vacuum pans are both complicated and expensive, they are coming into use for the refining of sea salt because they result in the finest product. This process makes use of the lowering of the boiling point of a liquid by decreasing the atmospheric pressure above it. It is impossible to attain nearly complete exhaustion of the chamber above the pan, but the partial vacuum maintained effects an appreciable lowering of the boiling point and a distinct saving in fuel. In the multiple-effect vacuum-pan system each pan acts, not only as an evaporator, but also as a boiler, producing heated vapor or steam for boiling in the succeeding pan, and as the condenser for the pan immediately preceding.

In the multiple-effect pans the steam from the boiler plant, which has a temperature slightly above 212° F (100° C), enters the steam belt of the first vacuum pan and is condensed there. The heat from this steam is transmitted through the tubes and absorbed by the evaporating brine, which is under a vacuum of about 15 inches. As this brine boils, it gives off heated vapor which passes to the steam belt of the second vacuum pan. The temperature of this vapor, which is the same as that of the boiling point of the brine at a 15-inch vacuum, is approximately 175° F (79.4° C). If the liquor in the second effect is under a vacuum of 24 inches, the vapor at a temperature of 175° F (79.4° C) in the steam belt causes the liquor to boil. The vapor from the second effect is in turn led into the steam belt of the third pan, and so on. Triple-effect vacuum pans are commonly used for the recrystallization of salt since a fourth effect is seldom profitable. Inasmuch as the design and operation of the multiple-effect vacuum evaporators are highly specialized phases of salt manufacture, the details will not be discussed here. The size and design of a simple vacuum pan will be briefly discussed, instead.

The body, or shell, of the larger vacuum pans, which are greater than ten to twelve feet in diameter, is usually made of cast iron; in smaller pans steel is used. The tubes are made of either steel or copper. Steel, copper, or tobin-bronze are used for the construction of the tube sheets. The customary dimensions for the tubes in the smaller pans are 2½ inches (o.d.) by 48 inches. In the larger pans where the tubes are sometimes as long as 72 inches 2½-inch tubes are also used.

The capacity of a single-effect salt pan is, roughly, one 280-pound barrel of salt in twenty-four hours for each 2½ × 48-inch tube, or one 280-pound barrel of salt for each 2½ square feet of heating surface in twenty-four hours. In other words, the capacity of a single effect pan in barrels per twenty-four hours is approximately equal to the number of four-foot tubes that it contains. This figure can be considerably exceeded if the pan is clean and artificial circulation is resorted to.

The efficiency of salt pans is generally 70 to 80 per cent. Usually, the salt made for single effect is 12 to 14 barrels of salt per ton of coal; for double effect, 21 to 24 barrels of salt per ton of coal; for triple effect, 33 to 36 barrels of salt per ton of coal; and for quadruple effect, 42 to 46 barrels of salt per ton of coal. These figures depend upon the grade of coal used.

The chief difficulty encountered in the crystallization of salt in vacuum pans is the formation of a hard porcelain-like scale of gypsum on the inside of the vacuum pan. This scale, a very poor conductor of heat, greatly reduces the efficiency of the apparatus. However, once formed, its removal is a difficult opera-

tion, accomplished either by overheating the underlying metal to loosen the scale or by simply scraping it off.

The formation of scale may be avoided in several ways. Before the brine is run into the vacuum pans, a small amount of calcium chloride may be added and then heated in a grainer-like tank to a temperature of about 150° F (65.6° C). Or a small amount of trisodium phosphate may be sucked into the vacuum pans during the evaporation. The latter operation causes the precipitation of flocculent calcium phosphate, instead of troublesome gypsum.

A low brine level in the pans and violent agitation of the brine during crystallization produces small, fine grains of salt; whereas, a higher brine level causes coarser grains. The crystallized salt drops down to the bottom of the vacuum pan and may be drawn off intermittently or caught either in a "salt-catcher," "leg," or "elevator boot."

As the boiling brine is under a partial vacuum, the level of the brine in the elevator housing above the boot is lower than that in the pan. The salt, contained in a bucket conveyor, passes through the brine in the elevator housing, where it may be washed with a pure salt solution. After washing, it is conveyed in a centrifuge for partial drying and finally to a revolving cylindrical steam-heated drier, previously described.

Status of Processing. Although vacuum pan equipment is considerably more costly than grainers having the same capacity, it is generally used for refining because a salt of high quality can be produced with a fraction of fuel and labor cost. Grainer salt is preferred for butter, cheese, and certain other products.

American Grades of Refined Sea Salt

The following grades of refined salt are considered commercial California salts:

No. 1 Mill Salt. Treated and dried salt which is "three-fourths ground" size.

No. 2 Mill Salt. Salt which is the same as No. 1, although somewhat coarser.

Coarse Granulated. Treated and dried salt which has been ground to a size suitable for cooking and preserving.

Fine Granulated. Treated and dried salt which has been ground to a size suitable for table use.

Bakers' Fine. A grade which is finer than table salt and is used in dairies and some chemical industries.

Shaker Salt. Especially prepared table salt, containing finely powdered magnesium carbonate or some other substance to produce "free-running" salt.

The uses for the various qualities of commercial salts are indicated below:

Hide Curing. Coarse, solar salt.

Meat Packing. Medium coarse, flaky steam-grainer salt.

Sheep Salt. Medium fine, crushed solar, crushed rock, or coarse grainer salt.

Stock Salt. Coarse, cracked solar, rock, hydraulically pressed 50-pound blocks, coarse grainer salt.

Cheese Salt. Medium-flaky grainer salt.

Butter Salt. Light and medium-flaky steam-grainer salt. For butter and cheese a thin flake permeates better than vacuum or crushed solar salt and does not form local pockets of brine that imparts a stinging, over-salty taste. The more pounds of flakes which can be used for a given quantity of butter, the less costly the product; for salt is cheaper than butter.

Kitchen Salt. Flake grainer, kiln-dried, screened, ground and dried solar, or rock-salt screenings. Commonly called "table salt."

Shaker Salt. Vacuum pan, grainer flake, finest kiln-dried, small screened and usually powdered with carbonate of magnesia to keep it free-running. For dining-table use.

Fishery Salt. Pure, coarse, flaky steam-grainer salt, which is free from calcium and magnesium, should be used. The flakes take up the fish juices rapidly, allowing a faster rate of penetration. Magnesium and calcium in fish salt cause "case-hardening," which cures the outer parts but gives less preservative action inside, used for dry-salting butts of cod, haddock, cusk, pollock, etc.

REFERENCES

Anon., "The Story of Diamond Crystal Salt," St. Clair, Michigan, Diamond Crystal Salt Co.

Anon., "Production of Diamond Crystal Salt," *Food News,* **14,** No. 1, 2–13 (1948).

Anon., "The History of Salt," Chicago, Morton Salt Co., 1949.

Badger, W. L., and Baker, E. M., "Inorganic Chemical Technology," 2nd ed. New York, McGraw-Hill Book Co., 1941.

Brighton, T. B., and Dice, C. M., "Increasing the Purity of Common Salt," *Ind. Eng. Chem.,* **23,** 336–339 (1931).

Hyler, J. E., "The Production of Salt," *J. Chem. Education,* **12,** 203–207 (1935).

Lee, J. A., "Refining the Salt of the Earth," *Chem. and Met. Eng.,* **42,** 124–128 (1935).

Pask, A. H., "Salt, Its Production, Uses," *Eng. J.,* **24,** 529–531 (1941).

Phalen, W. C., "Technology of Salt-Making in the United States," *U. S. Bureau of Mines Bull.,* **146** (1917).

Robinson, C. S., "Salt Plant Design and Construction," *Can. Chem. Met.,* **19,** 324–325 (1935).

Shreve, R. N., "The Chemical Process Industries," New York, McGraw-Hill Book Co., 1945.

CHAPTER 4

Magnesium, Bromine, and Other Products from Sea Water

The Recovery of By-Products from Bittern

The Importance of By-Products. Although salt has been produced by the solar evaporation of sea water for many centuries, no important use has been made of the bittern or mother liquor from salt crystallizations until comparatively recent times, when Balard worked out the well-known process for the recovery of sodium sulfate and potassium chloride. This process, with modifications by Merle and Péchiney, is in use today at Giraud-en-Camargue, situated at the mouth of the Rhône River. Although Balard's process was entirely successful at the Giraud salt works, few attempts have been made to utilize salt bitterns elsewhere until recently. For a number of years magnesium chloride, magnesium oxychloride cements, and bath salts have been recovered from the bitterns obtained in the California salt works, and during World War I potassium chloride was taken from some salt works.

The discard of the mother liquors from the salt works represents a tremendous waste; the mother liquor from 100,000 tons of salt contains 2800 tons of potassium chloride, 27,300 tons of magnesium chloride ($MgCl_2.6_2HO$), 16,000 tons of magnesium sulfate ($MgSO_4.7H_2O$), and 240 tons of bromine.

Detailed analyses of various bitterns from some California salt works are given in Table 8.

Balard's Process. About the year 1850 Balard perfected the process, which bears his name, for the recovery of common salt, sodium sulfate, and potassium chloride from the solar-salt bitterns. His process, in general terms, consisted of alternately concentrating and cooling the mother liquor of the sea-salt works, so as to secure by successive crystallizations the three products mentioned and, also, a concentrated magnesium chloride solution. This process is described briefly in the following:

Bittern of about 1.28 sp. gr. (31.72° Bé.) was evaporated to a density of 1.32 35.15° Bé.); under such conditions it deposited magnesium sulfate containing almost an equivalent amount of sodium chloride. This *sels mixtes* was converted into nearly pure sodium sulfate and magnesium chloride by dissolving it in water and allowing it to crystallize during cold weather.

The mother liquor from the *sels mixtes* was held until cold weather when it was run into shallow concrete tanks; nearly pure magnesium sulfate was deposited. This magnesium sulfate was converted into sodium sulfate by adding 1.5 of its equivalent of sodium chloride and by dissolving it and allowing it to crystallize at a temperature below 32° F (0° C). Nearly pure sodium sulfate was obtained.

The mother liquor from the magnesium sulfate crystals was stored through the winter and evaporated further during the succeeding spring and summer. This

evaporation caused crystallization of potassium chloride with a portion of the magnesium chloride, which, combining to form an impure carnallite ($KCl.MgCl_2.6H_2O$), left little else in solution but magnesium chloride, which was discarded. A considerable proportion of potassium chloride was removed from the carnallite by washing, first with a potassium chloride solution, and then with water.

Merle and Péchiney improved Balard's process by making use of artificial refrigeration for the cooling of the liquors; moreover, they introduced other new features for the preparations of anhydrous sodium sulfate.

TABLE 8. ANALYSES OF BITTERNS FROM SEA WATER * †

	Serial No.						
	11B 198	11B 199	11B 200	11B 201	11B 202	11B 204	11B 205
K	8.2	13.4	13.2	14.6	21.5	35.0	11.8
Na	72.6	62.7	60.9	24.5	4.7	93.5	55.1
Ca	1.2	2.2	0.6	0.5	1.0	0.2	1.1
Mg	24.0	23.4	50.6	62.7	79.4	8.6	43.9
Cl	179.2	176.6	179.4	183.3	220.1	180.4	190.8
SO_4	30.0	31.4	53.6	74.2	62.0	29.0	55.8
Br	3.0	2.0	2.0	3.0	2.0	2.0	2.8
	Conventional Combinations						
KCl	15.6	25.5	25.5	27.8	41.0	66.7	22.5
NaCl	184.2	159.1	154.6	62.1	11.9	237.6	129.7
$MgCl_2$	77.1	84.5	11.8	176.3	256.9	5.8	132.9
$CaSO_4$	4.0	7.4	2.3	1.7	3.3	0.6	3.7
$MgSO_4$	33.9	39.8	65.0	91.5	75.3	35.8	65.4
$MgBr_2$	3.4	3.4	3.4	3.4	2.3	2.3	3.2

Description of Samples

11B 198. Leslie Salt Refining Works, San Mateo, Calif. Representative sample of mother-liquor from the near northwest corner of the mother-liquor pond.

11B 199. Leslie Salt Refining Works, San Mateo, Calif. Sample from the southeast corner of the mother-liquor pond.

11B 200. Leslie Salt Refining Works, San Mateo, Calif. Mother liquor from the salt-making pond (solar evaporator or "salt garden"); pond has been "making salt" during the summer.

11B 201. Oliver Salt Works, Mt. Eden, Calif. Mother liquor from slop pond, which represents a 5-year accumulation.

11B 202. Oliver Salt Works, Mt. Eden, Calif. Mother liquor which has been subjected to some special treatment.

11B 204. California Salt Co., Alvarado, Calif. Mother liquor from the slop pond, which represents about a three-year accumulation, with the subtraction of considerable quantities for "forcing" purposes and the addition of small quantities of other waste liquors.

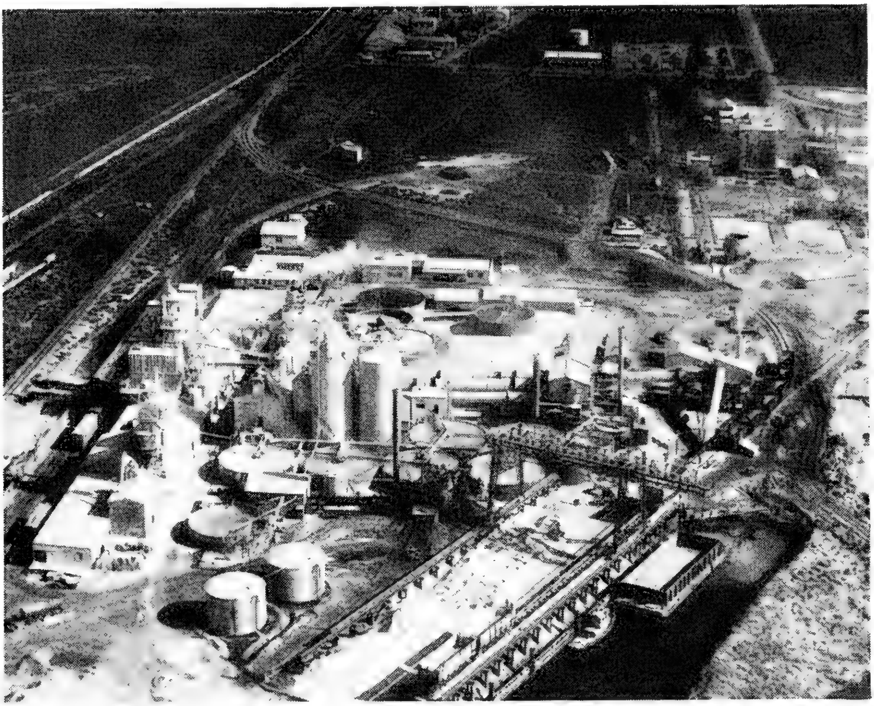
11B 205. Pioneer Salt Co., San Francisco, Calif. A year's accumulation of mother liquor.

The California Process. Little use was made of the bitterns obtained in the manufacture of solar salt in northern California until the event of World War I, when the high prices of chemicals and the general economic situation brought

* Turrentine, J. W., "Composition of the Salines of the United States," *J. Ind. Eng. Chem.*, 5, 19–24 (1913).

† Gardner, R. F., analyst.

about the utilization of waste products in many industries of this country. Among the by-products which have been prepared from the sea-salt bitterns, are magnesium sulfate, magnesium chloride, magnesia, milk of magnesia, magnesium carbonate, potassium chloride, bath salts, low-grade salt, magnesium oxychloride cements, and artificial stone. Metallic magnesium has been prepared on a small



(Courtesy Food Machinery and Chemical Corp.)

Fig. 4–1. The Newark, California, plant of the Westvaco Chemical Div., Food Machinery and Chemical Corp. Here bromine, gypsum and magnesia are produced from the bittern (mother liquor) which remains after the crystallization of solar sea salt.

scale during experimental work on the utilization of bittern, but its production was not commercially successful for economic reasons.

Since 1930 the bitterns from the solar salt operations of the Leslie Salt Company of California have been utilized chiefly for the manufacture of bromine, magnesia, and gypsum. Although the process, as now used by the Westvaco Chemical Co., is relatively simple chemically, it is a chemical engineering operation of the first magnitude.

Raw bittern is pumped from the storage pond to a mixing trough where sulfuric acid is added to lower the pH to about 4. The treated bittern is pumped to a measuring weir on the top of the bromine plant. At this point an anti-foaming agent and a little water are added. The bittern then enters the top of a stoneware tower and is distributed over the cross section of the tower. Chlorine and steam are passed upward through the tower which set free bromine which passes out the top. The bromine is recovered and purified by distilling. As the bit-

tern emerges from the bottom of the tower, milk of lime is added to neutralize a portion of the acid present. The treated bittern then flows into a concrete-lined pond until needed for magnesia recovery.

The first step in the recovery of magnesia from the bittern is treatment with calcium chloride brine, which produces a precipitate of gypsum ($CaSO_4.2H_2O$) and converts magnesium sulfate into chloride. After the separation of gypsum, a valuable by-product, the "magnesium bittern" is treated with lime, thus producing a precipitate of magnesium hydroxide which is flocculated, thickened, and washed in Dorr thickeners. This reaction regenerates the necessary calcium chloride brine for the treatment of more raw bittern. The washed magnesium chloride is separated in an Oliver filter and calcined at 1832° to 3272° F (1000° to 1800° C), thus obtaining magnesia (MgO). The lime used in precipitating the magnesium hydroxide is made by "burning" in a rotary lime kiln oyster shells dredged from the bottom of San Francisco Bay.

The gypsum crystals are separated, concentrated, and washed in Dorr thickeners. Then the gypsum is separated by Oliver filters, on which it is given a final washing. The gypsum filter cake drops into a paddle mixer which feeds a cage-type kiln mill and flash drying system. The dried gypsum is drawn into a "cyclone," from which it is carried by a screw conveyor to storage.

Minerals Direct from Sea Water

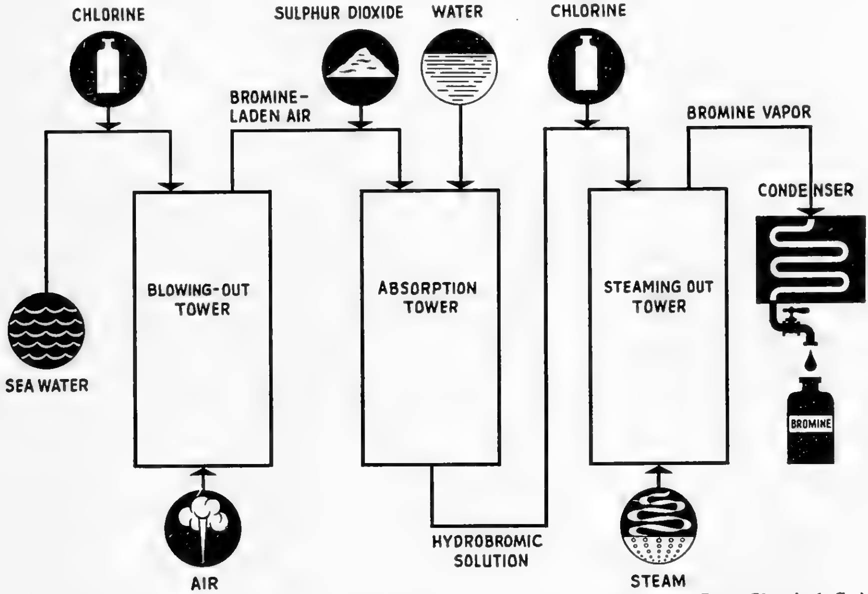
Introduction. In the ocean there is a vast store of minerals (pages 2 and 4) containing appreciable quantities of at least 50 elements which have been leached from the rocks and soil. For example, in a million pounds of sea water there are approximately 1000 pounds of magnesium and 65 to 70 pounds of bromine. In view of its almost limitless quantity, sea water is a very important potential source of these and many other elements. The difficulty, of course, is the necessity of separating the minerals from such a large quantity of water.

The ocean has long been an important source of sodium chloride (common salt) and, for the past century, certain other compounds have been obtained from the bittern as by-products from the manufacture of salt. But the separation of elements direct from sea water is an industry of recent origin, having started in 1924 when the Ethyl Corporation began extracting bromine in commercial quantities from the ocean. Similar extraction of magnesium was undertaken in 1928 by the Dow Chemical Company.

Bromine from the Ocean. In 1924 the demand for bromine increased greatly, owing to the need for ethylene dibromide to make "ethyl" gasoline. To obtain more bromine the operation of a small plant was begun on the Atlantic Coast; this produced tribromoaniline by the addition of aniline to chlorinated sea water. Later, this process was tried on a boat, but the high cost of the bromine produced did not make continuation of the venture worthwhile.

Meanwhile, the possibility of adapting the process used for the extraction of bromine from natural brines to the separation of bromine from sea water was being studied. In 1931 the Dow Chemical Company built a pilot plant in North Carolina in which 500 pounds of bromine per day were produced. Eventually, the Ethyl-Dow Chemical Company was organized for the purpose of manufacturing on a large commercial scale bromine and ethylene dibromide from sea water in a plant which was constructed in 1933 near Wilmington, North Carolina.

Briefly, the process involves: (1) acidulating sea water with sulfuric acid from a pH of 7.2 to approximately 3.5; (2) oxidizing the acidulated sea water with chlorine to free the bromine from the bromides; (3) blowing the free bromine out of solution with air; and (4) absorbing the bromine in a sulfur dioxide solution, by which the bromine is reduced to hydrobromic acid. The hydrobromic



(*Courtesy Dow Chemical Co.*)

FIG. 4–2. Flow sheet of the Dow process for producing bromine from sea water.

acid solution is treated with chlorine to free the bromine again by driving it out of the solution with steam and finally condensing it as a liquid. By this process half of the bromine in sea water can be economically recovered.

Metallic Magnesium from Sea Water. The Dow Chemical Company began the manufacture of magnesium from sea water at Freeport, Texas, on January 21, 1941. This was the first time a metal had been produced in commercial quantities from sea water. Since then the plant at Freeport has been greatly enlarged and another huge plant has been built at Velasco, Texas. The latter, government-owned, is no longer operating.

The Dow process involves the precipitation of the magnesium as hydroxide, the thickening and washing of this precipitate, the conversion of the magnesium hydroxide into chloride by neutralization with hydrochloric acid, the concentration of the chloride to a 35 per cent solution by evaporation, filtration of this solution, followed by further evaporation and drying, and finally the electrolysis of the fused magnesium chloride to produce metallic magnesium. The exact procedure is briefly described as follows:

The sea water is drawn from a canal through large grid and rotary screens into a flume and is pumped through a constant-head tank into a reinforced concrete flocculator tank where it is agitated with an excess of milk of lime. Precise control

of the mixing converts the magnesium chloride into a rapidly settling, easily filterable precipitate of magnesium hydroxide.

The treated sea water flows by gravity through a concrete duct to the center of large Dorr settling tanks or thickeners, each about 500 ft. in diameter. A Dorr thickening mechanism in each quadrant of the tanks plows the thick magnesium

(Courtesy Dow Chemical Co.)

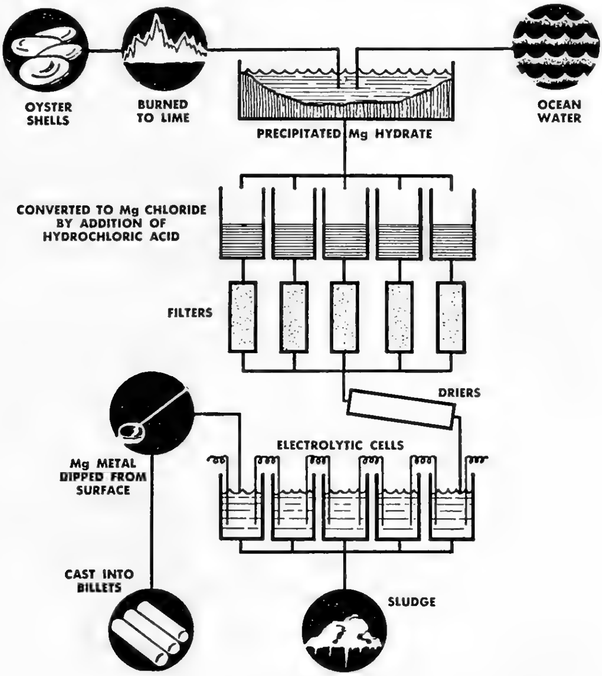
FIG. 4–3. The Dow Chemical Company's bromine plant at Freeport, Texas. In the left foreground is the ethylene dibromide plant and storage tanks. Just beyond these buildings is the flume leading in from the left through which sea water flows to the bromine extraction units which are comprized in the two large brick buildings. These buildings house the blowout towers where the chlorinated sea water is exposed to an air-blast. The elaborate piping system used for dispersing the sea water can be seen on the roofs of these buildings. Beyond them are the cylindrical absorption towers where bromine is reclaimed from the air stream. The smaller structures which look like dog houses surrounding these absorption towers are the entrainment separators or filters through which the air stream finally passes into the atmosphere. The effluent sea water passes out through a concrete flume which is visible beyond the intake flume. The water in the upper left-hand corner is a portion of the Brazos River.

hydroxide slurry to the center of the quadrant, whence it is pumped to a storage tank. This first step removes approximately 98 per cent of the water and its components and provides a slurry containing 12 per cent magnesium hydroxide and practically all the magnesium and most of the calcium and bicarbonates (now carbonates) of the sea water. The flow sheet (Fig. 4–4) graphically indicates the various steps in the process.

The crude magnesium hydroxide is then separated in Moore leaf-type filters. When the filter cake is about 2 inches thick on the outside of the filter cloths, the filter baskets are removed by a hoist from the filter pit. Air pressure is then ap-

plied to the header of the filter, causing the cake to drop into a dump pit. This filtration removes approximately half of the remaining water and soluble salts from the crude magnesium hydroxide.

The filter cake, which contains approximately 25 per cent magnesium hydroxide by weight, is mixed with a dilute magnesium chloride solution and "creamed"



(*Courtesy Dow Chemical Co.*)

FIG. 4–4. How the Dow Chemical Company produces magnesium metal from sea water.

to a slurry by agitation and homogenization. This mixture is pumped into tanks where it is neutralized with a solution of recycled hydrochloric acid containing a little sulfuric acid to a pH of 6.5. Part of the resultant 15 per cent magnesium chloride solution is returned to the dump pits for the creaming of the filter cake (crude magnesium hydroxide); the remainder is pumped into storage tanks.

The magnesium chloride solution is then evaporated by blowing hot gases (products of combustion) through it until a 35 per cent solution is obtained. Evaporative cooling in a vacuum cooler reduces the temperature of the hot concentrated solution to approximately 122° F (50° C). After cooling, it is passed to tanks where a solution of magnesium sulfate and chloride, made by the neutralization of the creamed crude magnesium hydroxide, is added in the amount required to precipitate the calcium from the solution as calcium sulfate. The liquor is held for 24 hours to permit crystallization of the calcium sulfate and sodium chloride. Then it is filtered through Moore filters similar to those used for

separating the magnesium hydroxide. The filter cake, which is a mixture of sodium chloride and calcium sulfate, is discarded.

Next the filtrate, containing 35 per cent magnesium chloride, is evaporated to 50 per cent concentration. This is accomplished in open brick-lined steel kettles and finally in shelf driers provided with raker arms which slowly agitate the product with circulating hot air, first at a temperature of 482° to 572° F (250° to 300° C) and then at 842° F (450° C). Finally, a free-flowing white granular solid, of the approximate composition $MgCl_2.1\frac{1}{2}H_2O$, is obtained.

(*Courtesy Dow Chemical Co.*)

Fig. 4–5. Precipitated magnesium hydrate is filtered out by means of these Moore filters in Dow's process for extracting magnesium from sea water. When the thick layer of hydrate has built up on the filter leaves, unit is moved by 100-ton crane to an adjoining compartment where the cake is removed by air-blast.

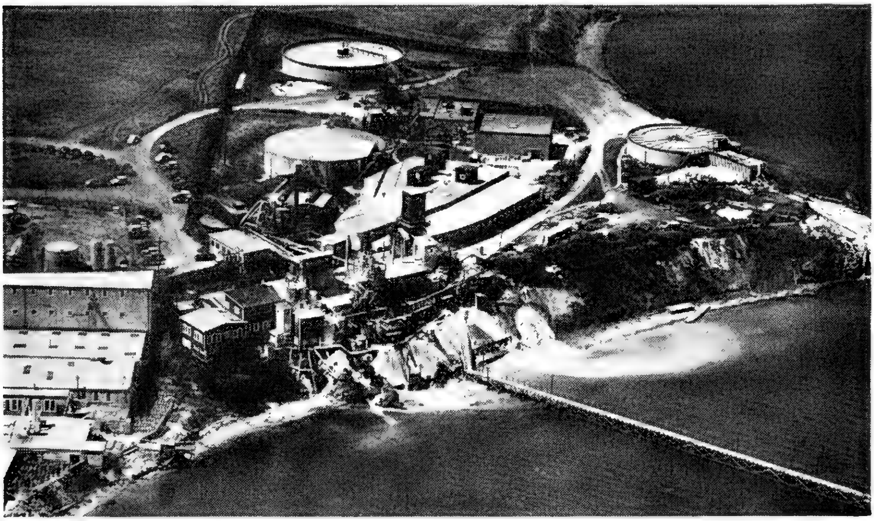
The magnesium chloride then passes to the electrolytic cells, each of which is full of a fused salt mixture composed of approximately 25 per cent magnesium chloride, 15 per cent calcium chloride, and 60 per cent sodium chloride at a temperature maintained between 1292° to 1382° F (700° and 750° C) by controlled gas firing. Magnesium chloride is continuously fed into the cells. The feed is melted by the heat of the bath and the residual water is evaporated. Passage of the 6-volt electric current between the graphite anode and the steel pot cathode electrolyzes the magnesium chloride, yielding magnesium and chlorine. The molten magnesium rises to the top of the cell where it is trapped by inverted troughs and directed to metal storage wells at the front. The hot chlorine gas and some of the hydrogen chloride produced by the reaction of chlorine with water are cooled and piped to the hydrochloric acid plant where they are converted to hydrogen chloride by reaction with steam and natural gas. As a small amount of chlorine does not reduce to hydrogen chloride, a controlled amount of sulfur dioxide is added to complete the conversion. The acid gases are absorbed in water in a scrubbing

tower and the resultant solution, containing 20 per cent hydrogen chloride and a small amount of sulfuric acid, is returned to the neutralizers to react with the crude magnesium hydroxide.

The plant at Freeport has a capacity of 36,000,000 and that at Velasco 72,000,000 lbs. of 99.9 per cent pure magnesium per year.

Magnesia and Magnesia Salts from Sea Water

The Marine Magnesium Products Corporation, established in 1927 at South San Francisco, produces magnesia, milk of magnesia, magnesium carbonate, and other magnesium products from sea water. According to the process used the



(Courtesy Dorr Co.)

FIG. 4–6. Plant of the Marine Magnesium Products Corp., South San Francisco, California. Here magnesia, milk of magnesia, magnesium carbonate and other magnesium products are made from sea water.

sea water is given a preliminary purification by treatment with a small amount of milk of lime and chlorine. After allowing the treated sea water to deposit sediment by standing in a huge tank, it is filtered through a gravity sand filter, then mixed with more milk of lime and run into another huge precipitating tank. Here, the magnesium hydroxide, formed by the interaction of the magnesium chloride of the sea water and calcium hydroxide, settles to the bottom and is pumped as a 12 per cent slurry to high tanks with conical bottoms where it is washed with softened fresh water. This reduces its salt content to approximately 0.05 per cent. After passing through a 325-mesh screen the magnesia is pure enough to meet U.S.P. specifications.

Some of the magnesium hydroxide is carbonated by treatment with CO_2, then removed from suspension by filtration and dried. Another portion of the magnesia is concentrated by the removal of water by filtration. It is spray-dried and finally calcined to obtain magnesium oxide.

From each 100 gallons of sea water approximately 34 pounds of magnesium

carbonate is obtained, representing a recovery of 80 per cent. The plant can treat 2,000,000 gallons of sea water in 24 hours; thus, its capacity is approximately 25 tons of magnesium oxide daily.

REFERENCES

Anon., "Sea Water Magnesite Plant Improved," *Pit and Quarry*, 33, No. 10, 45, 47 (1941).

Hunter, R. M., "The Electrochemistry of the Dow Magnesium Process," *Trans. Electrochem. Soc.*, **86**, 21–31 (1944).

Kirkpatrick, S. D., "Magnesium from the Sea," *Chem. Met. Eng.*, **48**, No. 11, 76–84 (1941).

Lawrence, A. A., "Vital Materials from Sea Water," Unpublished paper presented before sixth summer conference, N. E. Assn. of Chemistry Teachers (1944).

Schambra, W. P., "The Dow Magnesium Process at Freeport, Texas," *Trans. Am. Inst. Chem. Eng.*, **41**, 35–50 (1945).

Seaton, M. Y., "Production and Properties of Commercial Magnesia," *Am. Inst. Mech. Eng.*, **148**, 11–31 (1942).

Shigley, C. M., "The Plant of the Dow Magnesium Corporation at Velasco, Texas," *Metals Technology*, No. 88, 1–9 (1945).

Stewart, L. C., "Commercial Extraction of Bromine from Sea Water," *Ind. Eng. Chem.*, **26**, 361–369 (1934).

Sverdrup, H. V., Johnson, W. M., and Fleming, R. H., "The Oceans: Their Physics, Chemistry and General Biology," New York, Prentice-Hall Inc., 1946.

Trauffer, W. E., "Lime, Gypsum, and Magnesite Produced from Sea Water and Shells at New Plant in California," *Pit and Quarry*, **30**, No. 11, 43–63 (1938).

CHAPTER 5

The Red Algae of Economic Importance: Agar and Related Phycocolloids

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History

From time immemorial man has utilized seaweeds for food, medicine, and fertilizer. In the "Chinese Book of Poetry," written in the time of Confucius (between 800 and 600 B.C.), there is a poem that mentions a housewife who cooks seaweeds. These plants have been considered of medicinal value in the Orient since the time of Shen Nung, the fabulous father of husbandry and medicine, who is said to have lived about 3000 B.C.

Although development of the utilization of seaweed in the Orient has always been far ahead of its use in Europe, the value of Irish moss as a food and of kelps and rockweeds as fertilizer was known long before trade with the Orient resulted in the introduction of agar to the Western world. Agar was the first seaweed product to become an important item of commerce. At first a novelty food, it later found a place in a variety of products and processes. From the kitchen of Frau Fanny Hesse, whose husband worked with the famous German bacteriologist, Robert Koch, agar found its way in 1881 into the bacteriology laboratory as a gelling agent for culture media. As it became generally available for bacteriological purposes early in the twentieth century, many other uses were discovered.

Of the three most important seaweed products, agar, algin, and Irish moss gel, the latter two were developed in the British Isles. Ireland was the birthplace of the utilization of the well-known "carrageenin" from Irish moss, and it was in England that the nature and value of algin and alginates from kelps and rockweeds were discovered in 1884–1886 by E. C. C. Stanford.

The earliest use of Irish moss was as a gelling agent for desserts (blancmange and puddings), especially before gelatin was available in prepared form. American colonists brought with them the knowledge of the food use of Irish moss, but failed to recognize the seaweed from which it is prepared (*Chondrus crispus* [L.] Stackhouse). For many years they imported Irish moss from Ireland at a high price until a mayor of Boston, as the story goes, identified native Irish moss and suggested its collection. So the American industry was born over 100 years ago. In recent years the commercial production of Irish moss extractive in purified and dehydrated form has developed on a large scale in the United States. In fact the United States leads the world in the production of both Irish moss extractive

(carrageenin) and algin, the two most important seaweed products developed in the Western Hemisphere.

The third of the three seaweed products of prime importance, agar, is still produced in greatest quantity in Japan, where it originated centuries ago. However, it appears that with World War II the Japanese permanently lost their global monopoly on this product. War-generated agar factories developed in the United States (both Atlantic and Pacific coasts), Australia, and New Zealand. Since the factories in all three nations are still producing agar, they may not yet have been effected by the low prices and saturated market resulting from competition and economic pressure. At the same time their prospects are aided by new types of agar, by the many new uses that have been developed, and by improvements in production processes. The agar factories of Australia and New Zealand appear to have fared better since the war than those of the United States.

Classification of Algae

Plants included in the *Algae* group have long been classified as a subdivision of the phylum *Thallophyta* on the basis of the theory that *Algae* and *Fungi* (the other subdivision of *Thallophyta*) developed from a common ancestor. Recent work, which takes physiological characteristics into account, indicates that *Fungi* were derived from *Protozoa,* not from the *Algae* by degradation as the old classification assumes. Furthermore, most classes of the old sub-division *Algae* are now believed to have developed along separate phylogenetic lines, as suggested by the morphology of reproductive cells, pigmentation, and physiology. Wide acceptance of this view relegates the term *Algae* to the status of a purely artificial group and has established seven separate phyla of plants formerly included in the *Algae* group (Smith, 1938). All these phyla reproduce by means of single-celled spores and do not have flowers, fruits, or seeds. The conspicuous marine algae include the following four phyla:

Cyanophyta, the blue-green algae, are widely distributed in the ocean, in fresh water, and in soil. The individual plants are miscroscopic and are not commercially utilized.

Chlorophyta, the green algae, are most abundant in fresh water, but are also widely distributed in the ocean, with the greatest variety of marine species in tropical waters. They are of little or no economic value; however, some species are used as food in Hawaii, Japan, and the South Pacific.

Phaeophyta, the brown algae, are almost entirely marine and are characteristic of cold waters throughout the world although they occur in tropical waters as well. The giant kelps and abundant intertidal rockweeds of our northern coastal waters are of great economic importance as a source of alginates. They are considered in detail in Chapter 6.

Rhodophyta, the red algae, occur in greatest variety in tropical waters, but are also abundant in cold oceans. Of all the seaweeds certain genera of this group, from which agar and agaroids are obtained, have the greatest economic value, although the importance of the brown algae is rapidly increasing. While all of the red algae contain a characteristic red pigment, phycoerythrin, they often range in color from yellow-green to purplish black because of the chlorophyll (green) and other pigments present in them. Of approximately 2500 known species only about 50 are found in fresh water.

A characteristic of red algae, responsible for their economic value, is the development of complex colloidal carbohydrates as cell-wall constituents. Chemically, they are sulfuric acid esters of simpler carbohydrates, usually galactans. A great variety of this group of substances is found throughout the phylum, and it may be that each species develops a polysaccharide that is chemically different from any other. Most of these phycocolloids, as they are known, will readily form a colloidal solution when heated, and become a gel when cooled; examples are agar and carrageenin, or Irish moss gel. A few, such as the extractive from *Gigartina acicularis* (Wulfen) Lam., simply become more viscous when the solution is cooled or concentration increased.

Edible Red Algae

Very little seaweed, as such, is eaten in the United States. In the Orient, however, dried seaweed is an important part of the diet. In Hawaii natives are said to utilize over 70 species of algae as food, most of which are red algae. Among the poorer classes of people seaweeds constitute the principal vegetable portion of the diet. In the British Isles, and to some extent on the Atlantic Coast of the United States, *Rhodymenia palmata* (L.) Grev. and other species are washed and dried and eaten as a delicacy. Dulse, the common name for dried *Rhodymenia,* is available in cellophane packages in the large cities of the northeastern United States. Seaweeds are widely used as food throughout the East Indies and by the natives of New Zealand and Australia. In the West Indies their use is very limited despite their great variety. Dry *Gracilaria cornea* J. Agardh is sold as a gelling agent of foods, similar to Irish moss, in the shops in Barbadoes and possibly elsewhere in the West Indies. Seaweed gels are preferred to gelatin in the tropics as they set readily at room temperature (even above 90° F [32.2° C]) and, of course, do not melt at summer heat as gelatin does.

The Nori Industry of Japan. Of all the seaweeds that are dried and used as food (omitting seaweed extractives), the nori industry of Japan is the largest. Nori, or laver as it is known in English-speaking nations, is prepared from *Porphyra tenera* Kjell. Laver from other parts of the world may be prepared from any one of a number of species of this genus. In New England small quantities of *Porphyra atropurpurea* (Olivi) De Toni and *P. umbilicalis* (L.) J. Ag. are processed. On the Pacific Coast of the United States *P. perforata* J. Ag. is commonly used. Some of the latter has actually been exported to China in the past (Bonnot, 1931). Chinese-Americans processed 300,000 pounds of laver in 1929, according to Bonnot's data.

Because of its life history, *Porphyra* is one of the few seaweeds adapted to a form of cultivation. In most regions *Porphyra* appears in the fall when water temperatures become low enough to meet its requirements, grows luxuriantly during the winter months, and then disappears completely in the spring when water temperatures rise again. It reproduces by microscopic one-celled spores which are shed by the thousands from each plant. If these spores come in contact with a rough surface, they may lodge against it; if the surface is in the intertidal zone, germination occurs and a new plant soon appears.

Since the vast majority of *Porphyra* spores fail to encounter a suitable surface, the abundance of adult plants can be increased if additional surface for spore attachment is provided in water containing many spores. The Japanese method of

doing this is to place rows of bamboo brush or horizontal rope nets tied to stakes so that the rope is in the intertidal zone. These forms of attachment surface, placed in the water in mid-September just before the season's first plants appear, are soon covered with *Porphyra.*

Cultivation of nori in Tokyo Bay originated in the 1670's, but was not widely practiced until about 1800. As early as 1901 over 2000 acres of ocean floor were

FIG. 5–1. *Rhodymenia palmata,* the edible seaweed, dulse.

used for growing *Porphyra;* in recent years more than 12,000 acres are cultivated (Tseng, 1944).

Harvesting of nori begins each year in November or December and successive gathering is done, as often as growth permits, until April, when growth ceases and the remaining plants degenerate. Fresh nori is carefully washed and pounded to remove impurities and dried in the form of sheets. First-quality nori is jet-black and lustrous when dry. Japan's annual production averages 800,000,000 sheets, half of which is produced along the shores of the Chiba prefecture in Tokyo Bay. The total retail value of the average annual production is about $6,000,000.

To the average Japanese nori is a breakfast stand-by although it is often served at other meals, also. One popular preparation is "rolled rice balls," in which vinegared rice, vegetables, and mashed prawns or eggs are rolled in a sheet of nori which is then sliced into servings. Nori is also eaten by cutting the sheets into

small squares and warming them over a charcoal fire. One side of the square is then dipped into a flavored soy sauce and a portion of steaming rice placed on it.

Food Value of Edible Algae. Seaweeds are a poor source of energy for mankind because a large portion of the calories they contain are in an indigestible form (complex carbohydrates). Even in parts of the world where seaweeds are widely eaten, they are not a principal energy source, but are consumed along with more substantial foods. While they appeal to the oriental peoples as a delicacy, their nutritional value depends upon their vitamin and mineral content. The vitamin C content of some seaweeds has been shown to equal or exceed that of lemons (Norris, Simeon, and Williams, 1937), while the B_1 content compares favorably with that of many fruits and vegetables. In general the shallower the water in which an alga grows, the higher its vitamin C content, while the proportion of vitamin B_1 does not vary with depth. Vitamin C also varies with the season; in most cases it is highest during the warmer months or toward the latter part of the best season of growth (Lunde and Lie, 1938).

The genus *Porphyra,* from which nori or laver is prepared, was found to contain up to 140 mg of vitamin C and over 500 Sherman units of vitamin B_1 per 100 gm of fresh weight, the highest of any seaweeds tested. It is also a good dietary source of iodine, required for normal function of the thyroid gland. Another seaweed that is high in vitamin C content, especially in the fall, is *Rhodymenia palmata* (L.) Greville, from which the edible seaweed product dulse is made. Table 9 gives vitamin B_1 and C contents of a number of the common algae.

TABLE 9. VITAMIN B_1 AND C CONTENT PER 100 G FRESH WEIGHT OF SOME COMMON SEAWEEDS.*

	Vitamin C (mg)	Vitamin B_1 (Sherman units)
Alaria valida	53	250
Ascophyllum nodosum	62	
Fucus evanescens	24	
Fucus serratus	48	
Fucus vesiculosus	77	
Laminaria cloustoni	47	
Laminaria digitata	15	
Laminaria esculenta	29	
Laminaria saccharina	24	
Laminaria sp.		200
Enteromorpha sp.	15	trace
Ulva lactuca	46	400
Gigartina mamillosa	63	
Porphyra nereocystis	53	550
Porphyra perforata	60	500
Porphyra umbilicalis	83	
Rhodymenia palmata	49	

Rhodymenia palmata is used extensively in Scandinavian countries as a feed for cattle and sheep. These animals graze selectively on *Rhodymenia* when it is available at low tide. Farmers along the coasts gather *Rhodymenia* and sometimes

* Data compiled from Lunde and Lie (1938) and Norris, Simeon and Williams (1937).

wash it in fresh water. There are two factories in Norway where algae are chopped and dried for preparation as stock feed. Seaweed that has been pulverized and dried can be dialyzed in fresh water to remove excessive salt and then redried.

Funori: Seaweed Glue and Sizing. The red alga, *Gloiopeltis furcata* Post and Rupr,* is the basis for another important seaweed industry in Japan. "Funori" is the Japanese name applied to the dried, partially fermented, bleached raw material from which is obtained a viscous nongelling colloid that is completely soluble in warm fresh water. It is widely used for a number of industrial purposes in Japan although rarely seen outside the Orient. There are over 100 funori producers in Japan, centering around Osaka, who prepare about $1,000,000 worth of the dry seaweed annually. Actual extraction of the colloid is always done by the consumer as the seaweed, when properly prepared, is almost 100 per cent soluble.

Gloiopeltis grows on rocks in shallow water along the Pacific shores of Japan. The collection procedure is similar to that used for *Gelidium:* Long-handled rakes are manipulated from boats or divers gather the seaweed by hand. Collectors sell crude, dry *Gloiopeltis* to factories where it is cleaned, sprinkled, and redried on mats, and at the same time bleached. This treatment causes the plants to stick together so that they form thin sheets which are easily rolled up after final drying. The finished product is often marketed in rolls about 3 feet long and 6 inches in diameter. Processing of funori is done during the summer months, coinciding with the collecting season.

In addition to *Gloiopeltis* one or more species of the genera *Irideae* and *Chondrus* are also used as funori raw material (Tseng, 1946). Processing of these plants is similar to that of *Gloiopeltis,* but may involve steaming and soaking to render them more pliant and to facilitate their dissolution when used.

Funori is used instead of starch in laundering, as a sizing for paper and fabrics, in the preparation of water-base paints, such as kalsomine, as an adhesive, and as a hairdressing.

In California *Irideae flaccidum* is a seaweed of potential economic value, possibly as a cold-mix stabilizer. Its extractive is very similar to Japanese funori. According to Hassid (1933a, 1935, 1936) it is an ester of galactan involving a sodium salt. In this respect and in its physical properties it resembles the sodium carrageenate, "Viscarin," prepared artificially † by replacing the naturally occurring calcium, potassium, and magnesium with sodium.

The Irish Moss Industry

The Irish moss industry of New England represents the oldest seaweed utilization efforts in the United States. The earliest use of Irish moss (*Chondrus crispus* [L.] Stack.) began in 1835 when Dr. J. V. C. Smith, a former mayor of Boston, pointed out to his fellow citizens that Irish moss, which at that time cost $1 to $2 a pound as an import, grew in abundance along the rocky shores of Massachusetts (Smith, 1905a). Moss harvesting promptly began at Scituate and that town has

* Dr. E. Yale Dawson has pointed out (private communication) that *Gloiopeltis coliformis* Harv. and *G. intricata* Suring. are now regarded by most authorities as one species, *G. furcata. Irideae laminarioides* (Hassid, 1933) is probably *Iridophycus flaccidum* Setchell and Gard., but since *Irideae* is proposed for conservation over *Iridophycus,* it should be *Irideae flaccidum* (Setchell and Gard.) Dawson. The latter constitutes a new combination.

† Algin Corp. of America, 1949.

henceforth been the mossing center. By 1880 the price had fallen to about 3 cents a pound and about 450,000 pounds were gathered. In 1898 the output was 770,000 pounds, valued at $24,825; in 1902 740,000 pounds, valued at $33,300, were marketed. By 1919 production had decreased to 212,200 pounds, valued at $15,687, probably because of the increasing availability and cheapness of prepared gelatin and other substances for desserts.

Besides Scituate, other Massachusetts localities where moss is often harvested in quantity include Rockport, Gloucester, Marblehead, Nahant, Cohasset, Plymouth, White Horse Beach, Cuttyhunk Island, and New Bedford.

War-stimulated demand for domestic Irish moss led to the development of an important mossing industry in Maine in 1944 and 1945. The bulk of Irish moss production in Maine is obtained between York and Boothbay Harbor, principally in Casco Bay. Large quantities of moss occur also from Rockland eastward to the Narraguagas River, as shown by a survey conducted in 1947 by the Department of Sea and Shore Fisheries, although the area has not been exploited. Table 10 shows the total pounds, dry weight, and the total value of the Irish moss harvested in Maine from 1945 through 1948. Moss harvesters are required to purchase a state license in Maine (Maine, 1948). Portsmouth and Rye are the principal sources in New Hampshire.

Table 10. Quantities of Irish Moss, Dry Weight, and Value Harvested in Maine, 1945 through 1948.*

Year	Pounds	Value	Per lb.
1945	500,000	$10,000	$ .02
1946	972,975	17,460	.018
1947	1,643,607	40,070	.024
1948	1,483,721	29,675	.02

Small quantities of moss have been obtained at Block Island, R. I., and Montauk, New York. In recent years considerable amounts have been imported from two principal areas in the maritime provinces of Canada: between the strait of Canso and Malagash and from Richibucto Point to Point Escuminac. The southern shore of Prince Edward Island has also been a source of much high quality moss.

Table 11. Approximate Quantities of Dry Irish Moss Exported from Canada in Carload Lots from 1940 through 1946. Additional Quantities Were Exported in Smaller Lots.†

Year	Prince Edw. Island	Nova Scotia	New Brunswick	Total
1940	0	10,000	0	10,000
1941	208,000	53,000	0	261,000
1942	1,490,000	490,000	26,000	2,006,000
1943	722,000	155,000	0	877,000
1944	773,389	488,611	26,000	1,288,000
1945	665,979	513,000	0	1,179,000
1946	2,354,000	528,000	0	2,882,000

* Maine Department of Sea and Shore Fisheries.

† Needler, A. W. H., "Irish Moss Industry of the Maritime Provinces," *General Series Circ. 10, Atlantic Biol. Sta.,* Fisheries Research Board of Canada (1947).

In 1948 a survey of the eastern portion of Newfoundland was made by the Industrial Development Board, and moss was found to occur in good quantity in St. Mary's Bay, Trepassey Bay, along the Burin Peninsula near Marystown, in Placentia Bay at Ship Harbour and Placentia Sound, in Gander Bay on the north coast, and in several other localities. Moss was collected in Newfoundland from 1941 through 1943, and the quantities obtained are shown in Table 12.

TABLE 12. IRISH MOSS GATHERED, DRY WEIGHT, IN NEWFOUNDLAND, 1941–43.

Year	Pounds
1941	28,795
1942	15,506
1943	11,534

Prior to World War II large quantities of Irish moss were imported from Ireland, Scotland, and France. Although European moss has been regarded as superior, American users learned during the war, when they were obliged to obtain supplies from New England and Canada, that a moss of at least equal quality was available from the Atlantic Coast of North America. Apparently Irish moss from the more northern parts of its range produces an extractive of somewhat higher gel strength than that from the southern portion. Variation in the properties of North American Irish moss resulted in a lack of uniformity of the finished product. This constituted the principal problem during the change-over period of the early war years, but it was solved by research and laboratory control.

The Plant. *Chondrus crispus* is a low, bushy, rather rigid seaweed, composed of flattened, forked branches that vary considerably in width, usually from one-quarter to one-half inch. The height of the plant ranges from two to ten inches, depending largely upon its habitat. Plants exposed to wave action in the intertidal zone tend to be shorter and more densely branched. The color ranges from greenish in shallow, clear water to a blackish purple in deep or turbid water. The plants grow on rocks in tidal pools and from the lowest part of the intertidal zone to a depth of 50 feet or more, depending upon the clarity of the water. Its range along the Atlantic Coast of North America extends from New Jersey to Newfoundland and probably into Labrador. Although plants have been taken in trawls off Cape Hatteras, N. C., it is doubtful that they could grow so far south. Massachusetts represents the approximate southern limit of its economic abundance, and Newfoundland the northern limit of collectable quantities.

Life History. When Irish moss is torn loose from the rocks, usually the holdfast and some of the lower parts of the plant remain attached. These portions give rise to new branches and within a few weeks or months full-sized plants are formed. In the southern part of its range growth may be sufficiently rapid to permit two collections from the same area within one collecting season.

In addition to vegetative regeneration reproduction also occurs by means of one-celled, microscopic spores. *Chondrus* plants are of three different types from the standpoint of spores produced: male, female, and tetrasporic. Male and female plants produce their respective sex cells. A fertilized egg cell on a female plant produces in turn a mass of carpospores, which, when mature, are shed in the

water. Those which chance to lodge in a favorable place grow into plants which produce spores in tiny groups of four, known as tetraspores; such plants are termed tetrasporic plants. Mature tetraspores are shed in the water and in turn develop into either male or female plants. It is believed that of each group of four tetraspores, two are capable of developing into male plants and the other two into female plants. In general female plants produce their carpospores in the summer, while tetrasporic plants produce spores in the fall.

Collection. Irish moss is gathered from May until about the first of September. Old-fashioned methods are still used. The mosser goes out to the beds, usually in a dory, an hour or two before low tide. By means of a specially constructed rake he pulls moss from the rocks until an hour or so after the tide has begun to rise. The rake is composed of tapered steel tines welded to a crossbar so that their bases are very close and the space between the tines wedge-shaped. The angle of the rake and the 12- to 20-foot wooden handle enable the tines to be drawn horizontally across the bottom. Bunches of moss are wedged between the tines and torn loose. An experienced mosser can gather 400 to 500 pounds, fresh weight, of moss during the 3 to 4 hour period of one low tide.

Drying. Fresh moss is usually washed in large vats of running sea water with motor-driven agitators. Washed moss is then spread on portable racks or the beach to facilitate drying. Since rain would extract much of the gelose, loose moss is quickly raked into piles and covered and the racks are stacked in tiers. If a bleached product is desired, the moss is sprinkled several times with fresh or sea water. Each successive drying results in further bleaching. Factories that extract carrageenin and market it as a dehydrated, purified powder usually use unbleached moss as pigments are removed in the manufacturing process. If the moss is to be sold in its dry, crude form, or simply pulverized, a clean, bleached product is desired as it brings the highest price. Considerable quantities are marketed in small packages sold at retail. Moss sold for extraction of carrageenin is usually unbleached and is put up in 100- to 200-pound burlap-covered bales. Careful attention must be given to the moisture content of dry Irish moss. If the moisture exceeds about 28 per cent, deterioration by mold growth is very likely to occur; from 15 to 18 per cent is considered ideal. Moss that is too dry is brittle and difficult to handle. Estimate of moisture content is done with good accuracy by those experienced in the drying and packing process.

Approximately 4 pounds of fresh moss are required to produce 1 pound of dry, unbleached (black) moss of average moisture content; about 5 pounds, fresh weight, are required to produce 1 pound of bleached moss. A large proportion of salt is lost from the bleached moss and sometimes a small portion of the most soluble fractions of its gelose content. Bleached moss also contains a lower average moisture content because more of the sea salts have been removed.

In 1948 and 1949 fresh moss sold for 2 cents per pound. Moss harvesters prefer to sell it in this condition, but the market is limited because it must be spread and dried promptly or deterioration will take place. Therefore most moss is dried by those who harvest it. Dried moss brought 8 to 12 cents per pound in 1948 and 1949. If bleached, the price range was from 12 to 15 cents. Prime quality bleached moss brought from 24 to 39 cents per pound in 1947.*

* Anon., "Agar-Agar and Irish Moss (*Chondrus*)," *World Trade in Commodities*, 5, No. 89, Part 2 (1947).

The Manufacturing Process. Production procedures vary among Irish moss processors in many minor details and in a few major respects. In general the procedure outlined in the following is that used by a factory at New Bedford, the largest processor of Irish moss in the United States.

Bales of raw material are first sampled by laboratory technicians to determine the nature and amount of the carrageenin content, an important step in maintaining uniformity of the finished product. The moss is then added to the cooker where it is briefly washed with cold fresh water to reduce the salt content and remove other impurities. In cooking 2 to 4 parts of dry seaweed to 100 parts of water are used, depending upon the results of the test on the raw material.

(Courtesy McGraw-Hill Publishing Co.)

Fig. 5–2. The first step in the manufacture of Irish moss extractive is to blend various lots of the dried "moss" in accordance with laboratory analyses. Then it is fed through a tube that empties into a cooker on the floor below.

When a batch has finished cooking, the carrageenin solution and seaweed residue are separated by a centrifuge and the residue is saved and cooked again. The partially clarified solution, containing 0.8 to 1.0 per cent carrageenin, is sent to stainless steel filter-slurry tanks in which it is constantly agitated while diatomaceous earth filter aid and activated carbon are added. It is next pumped through a plate-and-frame filter press to another tank. Filter aid is again added as the solution is agitated, and the liquid is sent through a polishing filter. In the vacuum evaporators about half of the water is removed, increasing the carrageenin concentration to about 2.0 per cent. The solution is then fed to chrome-plated, double-drum driers from which it is scraped in the form of dry flakes as the drums revolve. The moisture content at this stage is only about 5 per cent. The flakes are passed through a rotary cutter and finally ground in a micro-pulverizer. Since the proper-

ties of the extractive in each batch are carefully determined by the laboratory staff, proper mixing of various batches is done in packaging in order to obtain a finished product of precise specifications. A final laboratory check is made of the blended material before it is distributed to the user. Many refinements have been added to the process, some of which are trade secrets, in order to obtain a higher yield, lighter color, controlled viscosity and gel strength, and other favorable

(Courtesy McGraw-Hill Publishing Co.)

FIG. 5–3. A large basket-type centrifuge separates the carrageenin solution from the seaweed residue after cooking is completed. The seaweed residue is saved and cooked again.

properties. A yield of from 60 to 80 per cent is obtained from the clean, thoroughly-dry raw material. Most of the ultimate residue is cellulose.

Although a white and highly purified finished product can be obtained by precipitation with alcohol (following filtration and concentration by evaporation), the cost of this procedure is prohibitive. Freezing out Irish moss gel, as is done in the manufacture of agar, is also unsatisfactory because of the tendency of carrageenin to reabsorb large quantities of water at low temperature.

The yield and properties of carrageenin vary with the season of collection and with the locality. The highest yield is obtained from moss collected in mid-summer, at the height of the harvesting season, while the lowest gelose content occurs in winter (Butler, 1936).

Chemical Nature of Carrageenin. The extractive from Irish moss is fundamentally similar to agar in that both are sulfuric acid esters of galactan. One of the principal differences is the greater complexity of the carbohydrate portion of the agar micelle, with the result that carrageenin has a much higher ash content and a lower gel strength. Carrageenin also contains a small percentage of Z-keto-gluconic acid.

The ethereal sulfate nature of carrageenin is well-established, but there is disagreement among investigators as to its exact nature. Although its carbohydrate portion is principally galactose, glucose and pentose have been found in small

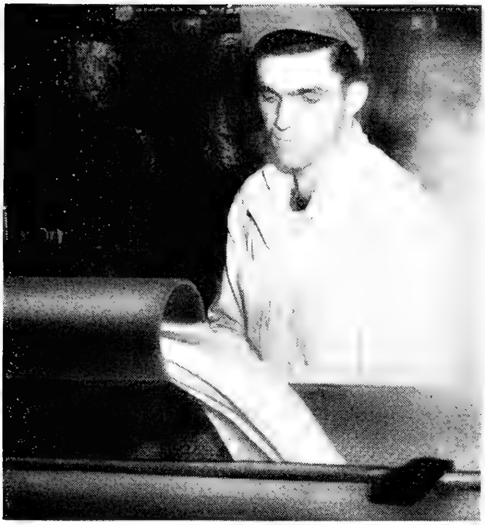


Fig. 5–4. Coming from the centrifuge, hot carrageenin solution of about 1.0 per cent concentration flows into a storage tank where diatomaceous earth filter aid is added preparatory to sending it to the filter presses. The solution is kept hot by steam coils.

(Courtesy McGraw-Hill Publishing Co.)

(Courtesy McGraw-Hill Publishing Co.)

Fig. 5–5. This close-up of one of the drum dryers shows the sheets of bone dry carrageenin being scraped off as the drum rotates.

quantities. Buchanan, Percival, and Percival (1943) found that the galactose residues are joined by 1,3-linkages. The sulfuric ester group is attached to C_4, and not to C_6 as in agar.

Haas and Hill (1921) first pointed out that carrageenin contains at least two different colloids, one soluble in cold water and the other soluble only in hot water. Buchanan, Percival, and Percival believe that the essential difference between the types is that the hot water extract is chiefly a calcium salt and the cold extract chiefly a mixture of sodium and potassium salts of carrageenin. They found glucose, however, only in the hot water extract. Russell-Wells (1922) offered evidence that the cold water extract consists of calcium and ammonium sulfates. She prepared ammonium salts of both extracts by treatment of the solutions with ammonium phosphate or ammonium oxalate, which causes a replacement of the calcium with ammonium due to the formation of insoluble calcium phosphate or calcium oxalate. The ash content of the resultant ammonium carrageenate was only 5.87 per cent, as compared with 21.26 per cent in the original, purified extract. Even after extensive purification a small quantity of nitrogen (about 1.0 per cent) remains in carrageenin, although it is not a part of the carrageenin molecule. In what form it occurs and why it is difficult to remove are not known.

Properties of Carrageenin. The principal properties of carrageenin are profoundly affected by the nature and relative amounts of other solutes contained in a solution of carrageenin in water. Theoretically, a pure carrageenin solution will not form a gel even if it is cooled to the freezing point. It is quite possible to prepare solutions of sufficient purity that apparently do not form a gel when cooled although the viscosity behavior at lower temperatures may be in part a manifestation of a form of incipient gelation.

Since agar and carrageenin do not have the same properties, they have different uses. Agar is best suited to uses in which the tendency to form a firm gel is required; indeed this is the property for which it is best known. Carrageenin is superior for uses which require high viscosity and the concomitant thickening, emulsifying, and suspending properties. In some cases, however, carrageenin is used for its gel-forming property.

Solutes present in a colloidal solution of carrageenin compete with the colloidal micelles for water, with the result that the properties of the colloid are altered. In general the greater the quantity of solute, the higher the temperature of gelation and melting, and the greater the gel strength, the lower the viscosity of the melted solution. Not only are these properties affected by electrolytes (various inorganic salts), but also by organic solutes, such as sugars and alcohols, including glycerin and various glycols. Salts of various organic acids, such as potassium acetate or calcium lactate, are very effective. Among the simple inorganic salts potassium chloride is one of the most effective and, at the same time, not objectionable in small quantities in foods. Fig. 5–6 shows the effect of various concentrations of KCl on the temperature of gelation of "Krim-Ko" gel, a commercially prepared Irish moss extractive. The temperature of melting is only 7 or 9° F (4 or 5° C) higher than the temperature of gelation throughout the range. In Fig. 5–7 the gel strength of various concentrations of the same extractive containing 0.5 per cent KCl are indicated. Fig. 5–8 shows the gel strength of a 2.0 per cent solution of "Krim-Ko" gel with various concentrations of KCl.

Ordinarily, solutions of carrageenin are prepared by heating either dry Irish

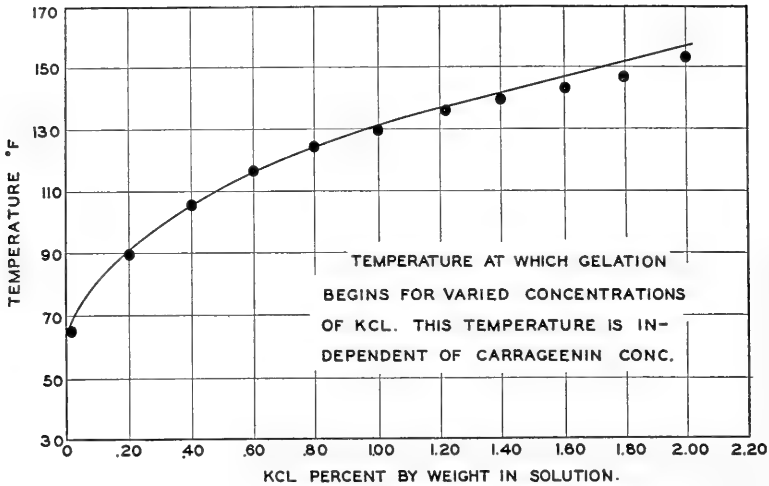


FIG. 5–6. Effect of various concentrations of potassium chloride on the temperature of gelation of Irish moss extractive. (*Data from L. Stoloff*)

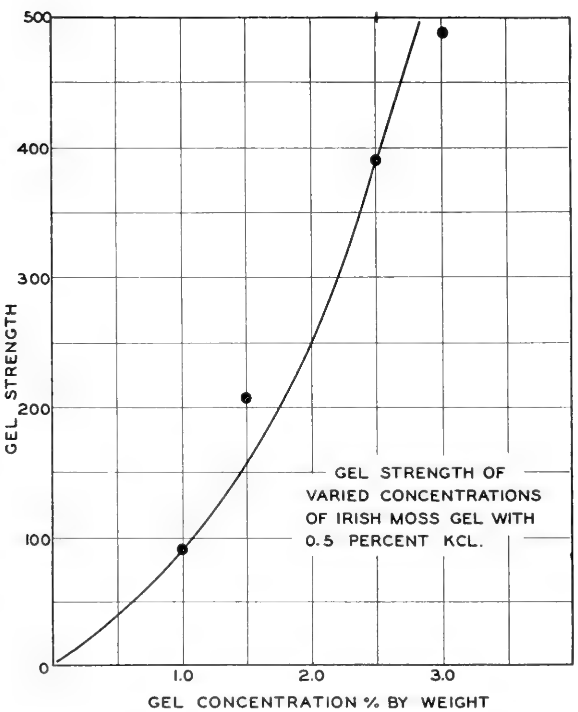


FIG. 5–7. Gel strength of various concentrations of Irish moss extractive containing 0.5 per cent potassium chloride. (*Data from L. Stoloff*)

moss or dehydrated extractive in water. Dissolution in cool water without the aid of heat can be accomplished if powdered carrageenin ("Krim-Ko" gel, for example) is dispersed in the desired volume of water and then sufficient acid added to reduce the pH to below 6.0 (Stoloff, 1950). Approximately 4 ml of 0.10*N* acid is required for every 2 gm of "Krim-Ko" gel. It will cause immediate

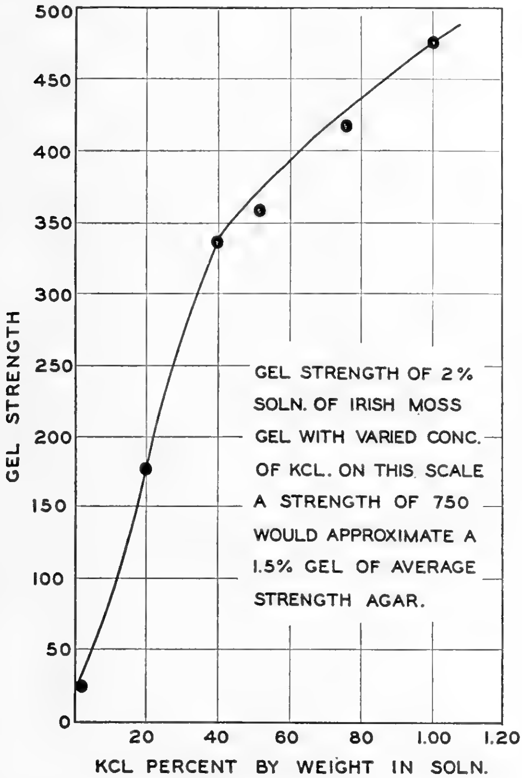


FIG. 5–8. The gel strength of a 2 per cent solution of Irish moss extractive with various concentrations of potassium chloride. (*Data from L. Stoloff*)

solution. Sufficient alkali to neutralize the acid may then be added. Solutions prepared in this manner are very clear and will gel only when high concentrations are used. Addition of salts, sugar, glycerin, or alcohol should be avoided until the gel powder has dissolved; after solution has occurred, it will result in an increase in viscosity. If a relatively high concentration of solute is added, the extractive may develop a pasty consistency. Carrageenin solutions prepared by this method exhibit all the useful thickening, emulsifying, and suspending properties obtained with hot process solutions. It is believed that salad dressings, relishes, and all sauces that contain vinegar may be stabilized more easily by this new method. Irish moss extractive may now be added to mixtures that cannot be heated.

The viscosity of liquid solutions of carrageenin varies, as do other hydrophilic colloids, with concentration and temperature. In addition viscosity of carrageenin solutions varies with the manufacturing process, with the procedure used to dissolve the extractive, with previous treatment of the solution, and indirectly with the concentration of various other solutes present. As a result the range of

viscosities of Irish moss extractive will run from 50 to 2500 centipoises at 104° F (40° C) in a 2.0 per cent solution; the viscosity of *Gelidium* agar of the same concentration is usually below 50 when the temperature is 104° to 113° F (40° to 45° C).

Pfister (1941) and Blihovde (1941) have pointed out in patents the manufacturing procedures that affect viscosity. Bungenberg-de Jong and Gwan (1929), who studied the effect of electrolytes upon the viscosity of carrageenin, found that the valence of the cation is of great importance and that as little as one milliequivalent of an electrolyte causes a detectable decrease in viscosity. Gutbier and Huber (1922) found that there was a progressive decrease in viscosity with the addition of HCl, NaOH, or NaCl; when a concentration of about 0.12N was reached, further addition of the electrolyte did not affect viscosity. The maximum amount of an electrolyte that is effective is related to the concentration of the colloid.

According to Stoloff (1948b), for temperatures above 104° F (40° C) the viscosity of carrageenin solutions is related to temperature by the following formula:

$$T^2 = A - 46{,}000 \log V$$

where: T = temp. in ° F
V = viscosity
A = constant dependent on sample and units employed

Below 104° F (40° C) incipient gelation is usually a contributing factor to the viscosity of carrageenin solutions.

Types of Carrageenin Products and Their Uses. Most of the Irish moss extractives now produced are used in the making of prepared foods, cosmetics, and pharmaceuticals. The value of carrageenin and other seaweed colloids in these products is due to their remarkable thickening, suspending, emulsifying, gelling, and stabilizing powers.

The properties of Irish moss extractives can be greatly modified, not only by the method used in manufacture, but by (1) the amount and kind of inorganic salts which it contains, (2) the amount and kind of other organic compounds (e.g., dextrose, sucrose, etc.) which it contains, and (3) its relative acidity (the pH of its aqueous solutions).

Several American companies * manufacture and market both unstandardized Irish moss extractives and specially prepared products designed for particular uses. They market these Irish moss extractives under various trade-marks, some of which are the following: "Carragar", "Carragarenin", "Gelcarin", "Gelloid", "Kimgel", "Krim-Ko" gel, "Krim-Ko" tendergel, "Krim-Kolloid", and "Viscarin".

At present the most important use of Irish moss extractives is as a stabilizer in chocolate milk. It also finds extensive use in other food products: various prepared cheeses, ice creams and ice cream toppings, sherbets, salad dressings, fruit syrups, flavoring emulsions in bakery products (especially icings and pie fillings), milk puddings and other desserts, jellied poultry and fish, aspic gels, jellied consommé, and confectionery. Other uses include making various pharmaceuticals (especially

* Important manufacturers of Irish moss extract include: Algin Corp. of America, New York City; Krim-Ko Corp., Chicago; Jacques Wolf and Co., Passaic, N. J., and Kraft Foods Co., Chicago.

emulsions and tablets), oil emulsions, insect sprays, and water-base inks, sizing cloth and paper, and creaming rubber latex.

In addition to the prepared extractives the seaweed itself is still offered in pulverized form for use as a clarifying agent in breweries. Carrageenin has the property of reacting with proteins in a manner that hastens coagulation and causes precipitation. This settling gelatinous mass also carries with it other particulate matter. It is added to hot beer wort (5 to 7 pounds per 500-barrel kettle) and a general precipitation soon follows. A second protein coagulation and precipitation occurs when the liquid has cooled to about 60° F (15.6° C), which brewers call the "cold break." Removal of proteins previous to fermentation produces a beer of superior flavor.

In applying an Irish moss extractive it should be remembered that, for many purposes, it is important to use a product which is easily soluble in water, has proper relative acidity (pH), and contains the proper amount and kind of inorganic salts to make it suitable for the purpose intended.

New uses for Irish moss and other phycocolloids are constantly being developed. Research is now directed to developing a superior dental impression compound using as the base carrageenin of carefully controlled properties. Agar and certain forms of alginate serve this function. The market for carrageenin is stimulated by the endeavor of manufacturers to develop a suitable form of extractive for specific uses for which no currently produced type is satisfactory.

Agar

Agar, in the form of a sweetened and flavored gel, has been an important part of the diet of oriental peoples for several hundred years. The accidental discovery that agar can be purified and dehydrated in one treatment occurred about 300 years ago when a Japanese innkeeper noticed that some agar gel he had discarded during cold weather had frozen, and, upon thawing, lost most of its water so that it dried readily in the sun to a fluffy white mass (Tseng, 1946). He found that a gel could be made from it as easily as from the original seaweed. His discovery led to the establishment (about 1769) and rapid growth of the agar industry in Japan. Dehydrated agar was easily and profitably exported. As early as 1903 there were 500 small agar factories in Japan with an average capacity of about 4000 pounds per year each (Smith, 1905). Prior to World War II the Japanese held virtually a world monopoly on the product.

Definitions. The term, agar, is most frequently applied to gel-forming extractives of red algae that are similar in properties, especially in gel strength, to the Japanese product made principally from *Gelidium amansii* Lamour,* or to California agar made from *Gelidium cartilagineum* (L.) Gaill. It will always be generic in common usage, and efforts to limit it to the extractives of two principal *Gelidium* species are not likely to succeed. The following definition of agar, the fundamentals of which were proposed by Tseng (1944), seems to be generally acceptable: Agar, the gel-forming extractive of *Gelidium*, *Gracilaria*, and

* *Gelidium corneum* appeared early in the literature on agar as a principal source. The name has been copied by successive authors and appears in government publications and the U. S. Pharmacopoeia. However, agar has never been made from *G. corneum* and it is safe to say that it never will be on a commercial scale. The species is so small and the plants so scattered that it is inconceivable that sufficient quantities could be gathered.

other red algae, is insoluble in cold water but soluble in hot water, a one per cent solution of which forms a firm gel.

Since gel strength is the most important property of agar, the definition may be improved by designating a "firm gel" as one in which a freshly cut surface will support at least 50 gm of weight when added at the rate of 0.5 gm per second through a plunger having a circular area of one square centimeter. Gels from

FIG. 5–9. *Gelidium cartilagineum* from which agar is made in California and Mexico.

Irish moss, *Gigartina, Agardhiella, Gloiopeltis, Phyllophora,* and some species of *Gelidium* and *Gracilaria,* which do not meet this requirement, may be referred to as agaroids.

Originally, the Malayan term "agar-agar" was used to refer to the seaweed *Eucheuma muricatum,* especially in dried form. *Eucheuma* yields an agaroid. Since Irish moss gel and other agaroids have also been called agar, it is advisable to determine an author's meaning of the term. It is, however, becoming more precise in its use, conforming to the above definition.

The Japanese Agar Industry. Raw material for the agar industry in Japan is obtained from the entire coastline of the main island of Honshu. Surga Bay, in the center of the south coast, is the area of greatest yield. Of the thirty or more species of seaweeds utilized, *Gelidium amansii* is by far the most important. Other widely used species include *Gelidium pacificum, Gelidium japonicum, Acanthopeltis japonica, Ceramium hypnaeoides, Gracilaria confervoides, Gelidium*

lichenoides, Ceramium rubrum, and *Gelidium subcostatum.* As the majority of them yield an agaroid, they are used only as admixtures with *G. amansii,* or some other superior raw material. Table 13 lists what may be an ideal mixture of various seaweeds for making one batch of agar.

Table 13. Ideal Proportions of Various Japanese Seaweeds for One Batch, According to the Japan Agar Distribution Control Company.*

Species	Per cent
Gelidium amansii	45
Gelidium japonicum	10
Acanthopeltis japonica	5
Ceramium hypnaeoides	10
Gracilaria confervoides	15
Ceramium rubrum	5
Gelidium subcostatum or *G. tenue*	10

Harvesting Methods. Gelidium amansii occurs from the intertidal zone to a depth of 60 feet or more, the best beds being located in deeper water. Since the plants grow firmly attached to rocks, they must be pulled off by hand or by means of special rakes. Most of the *Gelidium* is gathered by hand by divers, wearing goggles or, in deeper water, full diving suits. Fishermen and their families are issued seaweed collecting rights by a Central Federation of Fishermen's Cooperative Associations, which gives individuals or local associations exclusive rights to specified areas (Adams, 1947). The harvesting season is from April to September.

Freshly gathered seaweed is spread to dry on bamboo racks along the shore. Partial bleaching occurs if the seaweed is sprinkled with fresh water or rained upon after it has been once dried. When dry, it is stored in sheds or barns where it can be kept indefinitely.

Japanese Factories. There are approximately 600 small agar factories in Japan, most of which operate only from early December to about March 1, with an average of 70 production days per annum. The average factory produces from 75 to 125 pounds of agar per day. The largest Japanese factories produce about 10,000 pounds per year.

Japanese agar factories are small because of the lack of machinery and cheapness of labor. The majority are located in the cool highlands of central and northern Japan, where the air is dust-free and winter weather such that agar gel will freeze when placed outside. Only a few factories are equipped with mechanical freezing machinery.

Processing Methods. Dried seaweed is shipped by rail from coastal areas to processing plants. A batch to be extracted is soaked in cold water in outdoor concrete vats to effect bleaching and cleaning. Further cleaning and washing are done in a vat in which the seaweed is pounded by mallets attached to an overhead eccentric shaft to remove calcareous incrustations and shells. Some factories are equipped with washing machines.

The desired mixture of various seaweeds, totalling 200 to 500 pounds, dry weight, is added to a tank of boiling water heated by a brick firebox in which

* Adams, C. M., "The Japanese Agar-Agar Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet,* 263 (1947).

wood is burned. When the water again comes to a boil, sufficient sulfuric acid is added to bring the pH just to the acid side of neutrality (about 6.0). After an hour or two of boiling those seaweeds which yield soft gels are added to the mixture and the batch is simmered for another 12 hours.

Japanese producers emphasize the importance of certain mixtures (Table 13) of seaweeds for obtaining a high quality agar. The fact that American factories obtain unexcelled agar by using pure *Gelidium cartilagineum* in California and

(Courtesy Japan Agar Distribution Control Co.)

FIG. 5–10. In Japan agar which has been allowed to gel in wooden trays is cut into bars and placed outside to freeze.

Gracilaria confervoides or *G. foliifera* (except for inadvertent contaminating species) in North Carolina indicates that the Japanese add other species because they are cheaper, or because the resulting gel has qualities desired for use as a food. Since the admixture of soft gel species reduces gel strength and probably increases elasticity, the resulting product is probably less suitable for bacteriological and certain industrial uses than agar from pure *Gelidium amansii.*

When cooking is finished, the solution from a second extraction of a previous batch is added. As the solution cools, the seaweed residue slowly settles, and the liquid is dipped off the top and poured into straining tanks that have perforated bottoms and are lined with a straining cloth having about 20 meshes per linear inch. The filtered liquid runs into a collection tank from which it is again dipped and poured into shallow wooden trays, holding 14 liters each, to solidify. A rake-type knife is used to cut the gel into bars. These bars are then placed outdoors to freeze and thaw. In some cases the bars are first pushed through a screen which cuts the agar into square straws. These, when dry, form the familiar strip or shredded agar.

When hydrophilic colloids are subjected to freezing temperatures, the force of hydration is broken. The water held by the colloidal agar particles separates from them in the form of ice crystals. In the case of those colloids in which hydration takes place at low temperature, hydration, or reabsorption of the separated water, will occur almost as fast as the ice melts and there will be little or

no final separation of free water. In the case of agar, however, full hydration or the formation of a colloidal solution occurs only when the temperature is 176° F (80° C), or more. Thus, when agar ice is melted, most of the water involved in the solution runs off. Only that amount (approximately) is held by the agar which dry agar would absorb if soaked to a state of equilibrium in cold water. With an agar gel of one to two per cent concentration 70 to 80 per cent of the water is lost in freezing and thawing. With this water, as it runs off, go 70 to 80 per cent

(Courtesy Japan Agar Distribution Control Co.)

FIG. 5–11. According to the time-honored Japanese method, agar strips which have frozen are thawed and partially dehydrated and allowed to dry in the sun.

of the soluble salts and pigments that were in the original agar solution. Thus, freezing and thawing are the most efficient means of purification and dehydration, especially since both results are accomplished simultaneously. With Irish moss and other soft-gel seaweed extractives most of the water is reabsorbed as melting occurs so that freezing is not feasible. All degrees of water loss, from 0 to 80 per cent, are to be found among various phycocolloids when frozen and thawed.

Yield. The yield of finished products from seaweeds is almost always expressed as a percentage of the air-dry weight of the raw material. The raw material usually contains from 10 to 20 per cent moisture when it is ready for processing. Different species of seaweeds yield different amounts of phycocolloid. In general those that produce a soft gel yield considerably higher than those that produce agar of high gel strength. The range of commercially used species runs from 15 to 80 per cent, or more. In the case of *Gloiopeltis,* from which "funori" and sizing is made, the raw material is almost completely phycocolloid, except for its moisture content. The yield of Japan's principal agar source, *Gelidium amansii,* ranges from about 20 to 35 per cent. Part of this rather wide range arises from the seasonal variation in agar content and part from the efficiency of extraction in the process used. Where a yield of 45 per cent is obtained by a careful laboratory analysis of a raw material sample, the factory yield of the same material may be only 25 per cent, sometimes less. A commercial process never extracts all the

agar from the raw material; the yield obtained ordinarily represents an optimum with respect to the cost of production. The optimum is established by the efficiency of the production process.

Although all seaweeds probably vary with the season in phycocolloid content, little experimental data are available on the subject. Aoki (1940) found that in Japan *Gelidium amansii* has the highest agar content in the spring and the lowest in summer when most of the harvesting is done. Apparently the phycocolloid content is greatest during or immediately after the season of most rapid growth. This varies among species and with locality as well.

Grading of Finished Product. Management of agar production is vested in the Japan Agar Control Company, a government agency founded in 1938 (Adams, 1947). This organization grades all agar produced in Japan on the basis of moisture content, color, gel strength, insoluble matter, protein content, solubility, and other characteristics.

Gel strength is determined by placing a 1.5 per cent solution of agar in a small cup and allowing it to stand overnight at room temperature. A 100-gm weight that has a cylindrical, flat tip 1 square centimeter in area is placed upon the surface of the agar. If the tip does not rupture the gel surface, the agar is graded as No. 3, or better. Similarly, grade 2 must support a 200-gm weight and grade 1 a 300-gm weight. Agar that does not meet grade 3 requirements, or better, is not exported. Table 5 shows the standards that the three grades of Japanese agar must meet.

TABLE 14. CHARACTERISTICS OF THE THREE GRADES OF AGAR EXPORTED BY JAPAN.*

Grade	Gel Strength	Max. Per Cent of Protein	Max. Per Cent of Insolubles
1	300	1.5	2.0
2	200	2.0	3.0
3	100	3.0	4.0

(Gel strength here is the number of grams supported by 1 sq cm of gel surface when the weight indicated is added all at once.)

The wide range of variation of all the characteristics in Japanese agar is due primarily to the mixing of different species of seaweeds in different proportions (Table 13) and secondarily to the great number of agar factories, each with its own modification of the production process. A slight variation in pH during cooking has considerable effect upon gel strength. If the pH is relatively more acid, gel strength will be low, but extraction will be rapid and more thorough. Some species of seaweeds are more affected by a low pH than others.

Production and Export Data. Production of agar in Japan has risen steadily since its origin, especially from 1926 until 1940. During the war years there was a sharp decline. From 1926 until about 1933 over 75 per cent of Japan's agar production was exported. After 1932 home consumption increased at a much greater rate than exports, which actually declined from 1936 through 1945. In 1946 exports rose again along with production and were expected to reach normal by 1950. Production figures for 1926 through 1945 are given in Table 15.

* Adams, 1947.

TABLE 15. AGAR PRODUCTION IN JAPAN FROM 1926 THROUGH 1945.* FIGURES ARE TONS (2000 LBS.).

Year	Tons	Year	Tons
1926	1441	1936	2811
1927	1525	1937	2927
1928	1496	1938	2843
1929	1488	1939	2969
1930	1522	1940	3232
1931	1643	1941	2370
1932	1733	1942	2992
1933	2294	1943	1739
1934	2557	1944	1411
1935	2750	1945	789

The United States has been one of the heaviest buyers of Japanese agar. Except for the war years, the amount imported has increased as new uses were developed. The substitution of synthetic products has hardly begun in the case of agar and must be anticipated for the future. Table 16 shows quantities of Japanese agar sent to the United States since 1933.

TABLE 16. IMPORTATION OF JAPANESE AGAR INTO THE UNITED STATES FROM 1933 THROUGH 1946.

Year	Pounds	Value
1933	607,389	$ 49,600
1934	420,948	126,300
1935	449,556	161,840
1936	651,975	267,310
1937	669,570	368,264
1938	590,719	307,174
1939	497,077	378,385
1940	709,524	674,047
1941	565,904	551,029
1942	52,408	57,341
1943	30,441	31,632
1946	60,835	182,505

The American Agar Industry. *California.* The American agar industry originated in California in 1919 when Chokichi Matsuoka, familiar with the agar industry of his native Japan, completed experimental work showing that agar could be made from the *Gelidium cartilagineum* † abundant along the Pacific Coast of southern California and Mexico. He formed the American Agar Company, which began to produce significant quantities of agar in 1920 at Glendale, California, but was unable to compete successfully with the low cost of imported agar. Matsuoka was issued two patents, the first (1921) of which described a process essentially like the Japanese, except that mechanical refrigeration was proposed. The second (1923) dealt with rendering dry agar brittle enough to pulverize readily by coating it with a sugar solution and redrying it.

* Adams, 1947.

† Matsuoka claimed to have used "*Gloiopeltis*." This genus (*Gloiopeltis*) is not a source of agar, however. It is quite certain that he used *Gelidium cartilagineum.*

Matsuoka's business was sold in 1923 to John Becker, an American engineer, who greatly improved the process. Becker was issued four patents, one of which (1929) dealt with a highly mechanized general process and two (1929a, b) with dehydrating equipment. His ideas provided the fundamentals of the American methods as they are today. The American Agar Company struggled against the low price of Japanese agar, the annual output depending primarily upon market price, and in 1933 it closed. Shortly thereafter the building was taken over by the American Agar and Chemical Company under the direction of Mr. L. Small, who converted a major portion of the floor space to the processing and freezing of seafoods. Production of high quality agar has continued.*

In 1933 S. F. Corfield established the United States Agar Company at National City, California. Later he also acquired the American Agar and Chemical Company and served as its manager for a number of years until his death. The Marine Products Company, formerly American Agar and Chemical Company, was the only factory in California producing agar at the beginning of World War II.

The Agar Products Company, under the direction of E. S. Moorhead, was founded at Los Angeles in 1941. This factory was an active agar producer throughout the war and the period of agar shortage that followed. Since 1947 it has specialized in a highly purified, unbleached agar for special uses as the price of Japanese agar is too low to permit profitable domestic production of the ordinary U.S.P. grade. Two other smaller factories were organized soon after agar became a critical war material, but apparently ceased production when the importation of Japanese agar was resumed.

North Carolina and Florida. Classification of agar as a "critical war material" by the War Production Board in 1942 stimulated a search for agar raw material at the Duke University Marine Laboratory in North Carolina and at the Palm Beach laboratories of the Institutum Divi Thomae in Florida. Agar production on the Atlantic Coast was first undertaken on a commercial scale in 1943 at Beaufort, N. C. as a result of an announcement (Humm, 1942) that *Gracilaria confervoides* (L.) Greville was commercially abundant in that area. The factory was first known as the Van Sant Company, but was sold in 1943 to M. Wronker Stansfield and associates and changed to the Beaufort Chemical Corporation. Production facilities were improved and enlarged; however, when North Carolina seaweed resources proved to be inadequate for year-round operations in 1945 and 1946, the factory closed and was sold in 1947 to Sperti Foods, Inc. During 1949 the production capacity of the factory was doubled and many improvements made, particularly in dehydration.

Experimental work of the Institutum Divi Thomae in Florida in 1942 led to the establishment in 1945 of a factory at Jensen. Agar was produced on a small scale from *Gracilaria foliifera* (Forsskal) Borgesen collected in the Indian River in the vicinity of Jensen and northward. In 1948 larger supplies of *Gracilaria* were found at Sebastian. Coincident with the purchase of the Beaufort factory the factory at Jensen was discontinued, although collection of seaweed at Sebastian was intensified in order to build up a one-year supply of raw material at the Beaufort factory. Availability of raw material in North Carolina had been irregular and it appeared that only about a six months' supply per year could be obtained in North

* Thanks are due Mr. E. S. Moorehead for supplying information on the history of the California agar industry.

Carolina waters. In 1949 the factory had a capacity of 1 ton of dry seaweed per day (350 to 400 pounds of agar).

Seaweeds Utilized. In California the principal agar-producing seaweed is *Gelidium cartilagineum* (Fig. 5–9.) Two other species, *G. nudifrons* Gardner and *G. arborescens* Gardner, are used to a limited extent; but, since they grow in deeper water and produce a slightly inferior agar (with reference to gel strength), they are unimportant. Material collected from these species is mixed indiscriminately with *G. cartilagineum. Gracilaria confervoides* was once used in California; however, it has not been collected in recent years due to the relatively low gel strength of its agar. The same species on the Atlantic Coast (as presently defined) produces an agar of higher gel strength.

Yield. California manufacturers ordinarily obtain a yield of 15 to 20 per cent from the *Gelidium cartilagineum* of Pacific Coast waters. On the Atlantic Coast the yield of all species so far utilized, *Gracilaria confervoides, G. foliifera,* and *Hypnea musciformis,* has also ranged between 15 and 20 per cent on a commercial scale. Yields above 20 per cent are rare. Laboratory yields of carefully prepared raw material of these species range from 40 to 45 per cent or more. With *Gelidium* only about 3 pounds of fresh material are required to make 1 pound of dry material whereas with *Gracilaria* and *Hypnea* about 10 to 15 pounds are required. Thus the agar yield of *Gelidium* on a fresh basis is about 6 per cent while the yield of fresh *Gracilaria* or *Hypnea* is only about 2 per cent. *Gelidium cartilagineum* grows firmly attached to rocks in turbulent water and is consequently difficult and costly to collect in quantity. Fresh *Gelidium* is worth about $80 per ton, dry *Gelidium* about $350 per ton (Tseng, 1947).

In North Carolina and Florida *Gracilaria confervoides* and *G. foliifera* (*G. multipartita* J. Agardh; *G. lacinulata* [Vahl] Howe) constitute the principal raw material. At first *G. confervoides* was the only plant in North Carolina of which use was made, but in recent years *G. foliifera* has become of increasing importance. Although *G. confervoides* occurs in Florida, *G. foliifera,* collected from the Indian River, is more abundant. Agar from these two species is similar, but not identical. In general *G. confervoides* agar is of slightly greater gel strength and exhibits a lower viscosity as a melted solution. The gel strength of agar from *G. foliifera* from North Carolina is slightly greater than that of agar from the same species from Florida. Comparisons of *G. foliifera* agar from Florida, North Carolina, and New Jersey indicate that the gel strength is inversely proportional to the water temperature. The correlation is supported by observations of gel strength of *G. foliifera* agar from seaweed collected at different times of the year.

The quantity of seaweed collected during the first 4 years of the agar industry in North Carolina is given in Table 17. The figures are not indicative of quantities available during 1943 and 1944 as intensive collecting was not undertaken until

Table 17. Approximate Total Dry Weight in Pounds of Each Species of Seaweed Collected in North Carolina, 1943–1946. The Price was 10 Cents Per Pound.

	1943	1944	1945	1946
Gracilaria confervoides	100,000	275,000	120,000	20,000
Gracilaria foliifera			6,000	120,000
Hypnea musciformis			4,000	27,000

1945. Much greater quantities of *G. confervoides* were present in 1943 and 1944 than during the next 5 years.

Methods of Collection. In California virtually all commercially collected *Gelidium* is obtained by divers wearing a complete suit and working in a depth of 10 to 30 feet. *Gelidium cartilagineum* is always quite firmly attached to rocks from the lowest tide line to a depth of 50 feet or more. It is most luxuriant where the water is turbulent. The diver pulls the seaweed from the rocks by hand and places it in a rope-net basket that holds 60 to 70 pounds when full. Most diving is done between May and November and only on relatively calm days. During an average year there are 100 to 120 days when suitable weather conditions prevail. In a day a diver may make two or three descents of 1 to 2 hours each, with rest periods in between. A veteran diver may gather one and a half tons of *Gelidium* a day under ideal working conditions. The usual day's harvest for one diver is about 1500 pounds (Tseng, 1947). Although *Gelidium cartilagineum* occurs from San Francisco southward to Puerto San Bartholomé, its commercial abundance is restricted to the area from Point Conception, California to Magdalena Bay, Baja California (Mexico). The plant grows to a height of 4 feet, but is considered harvestable when it reaches 12 to 18 inches (Tseng, 1944). Most of the *Gelidium* processed in California during and following the war came from Baja California (Mexico), where production of agar raw material is about 10 times as great as in California (Anon., 1947). About 225 tons of dry *Gelidium* were imported from Mexico in 1948 for processing in California.

In North Carolina and Florida seaweed collecting is much simpler. All commercial species occur in great loose masses on shallow flats where the bottom is muddy or sandy and where the depth is from 1 to 3 feet at low tide. Collection is a matter of raking the seaweed into a skiff while the collector stands less than waist deep in water, the temperature of which is above 75° F (23.9° C), or even above 80 (26.7° C). In North Carolina some seaweed is obtained by placing nets across channels or narrows through which tidal currents flow. Just before the current changes direction, the net is lifted and the seaweed removed. In the fall, when the north winds begin along the North Carolina coast, large quantities of seaweed often wash ashore, especially on the bay beaches facing south. The winds cause a movement of water across the surface of the bay and a countercurrent is set up along the bottom. Since all economically valuable species, when loose, tend to rest on the bottom, the countercurrent moves them in a direction opposite that of the wind, with sufficient force to drive them up the slope of a beach, especially with a rising tide.

Life Histories. From an economic viewpoint *Gelidium cartilagineum* has a simple life history. It is essentially the same as that described for Irish moss (page 54). Spores produced by the three types of plants germinate and produce new plants if they happen to lodge on a favorably located rock. Mature plants are torn loose during storms and sometimes constitute a source of raw material; however, growth will not occur, as with *Gracilaria,* after dislodgment.

Gracilaria confervoides has a relatively complex life history in North Carolina, where it exists in two phases, one of which does not give rise annually to the other (Humm, 1950). One phase is typical of red algae in general and is the same as that described for Irish moss and *Gelidium:* Plants attached to stones or shells produce spores which in turn produce new plants if they lodge upon a favorable

substratum. This phase of *G. confervoides* is widely distributed in North Carolina and in temperate oceans throughout the world. In North Carolina, however, the attached, sporulating phase does not occur in sufficient abundance to be economically valuable, as it does in Australia and South Africa. The other phase is a loose, drifting, nonspore-forming plant that is not attached at any stage of its

FIG. 5–12. *Gracilaria foliifera,* the principal agar source in Florida, and an important source in North Carolina.

life history. It lies loose in shallow, quiet water, or drifts about as it grows. Reproduction is purely a matter of growth and accidental breaking apart of the plant, with continued growth of the fragments. In the fall plants of this phase accumulate in great masses in areas where tidal currents are not strong enough to sweep them out. At times the drifts may be 1 to 3 feet deep in water hardly deeper at low tide than the seaweed. As the water temperature falls to about 60° F (15.6° C), growth ceases and all plants in areas where waves and currents do not move them, gradually settle down, become semidormant, decay in part, and break into small pieces during the winter. In the spring (usually April) when water temperatures again become favorable for growth, all fragments that are still alive begin to sprout and soon become bushy and semibuoyant. In June some of the plants begin to drift and, as they become larger, are broken into small pieces. By July this purely vegetative phase is again widely distributed and has begun to accumulate in masses. Commercial collecting usually begins in August and reaches a peak in October. Although it would appear that the loose, drifting phase is derived annually from attached, spore-forming plants, there is no evidence that this occurs in North Carolina.

Gracilaria foliifera and *Hypnea musciformis* also occur in great loose masses, both in Florida and North Carolina. All these plants, however, were originally attached to a stone or shell where a spore lodged. When loose and drifting they continue to grow and produce spores just as do the plants that remain attached through maturity. Abundant production of spores by a plant appears to be accompanied by a physiological aging and ultimate degeneration, even under ideal growing conditions. Spores germinate soon after they are released if water temperatures are favorable. In the fall they apparently do not germinate, but spend the winter in dormancy and germinate the following spring. A few vegetative plants of *Hypnea* may be found throughout the winter in North Carolina, but very little growth occurs and little or no spore production. *Gracilaria foliifera* occurs in good vegetative condition during the winter in North Carolina and apparently grows slowly. Both *G. foliifera* and *Hypnea* reach a peak of abundance in June or July, with *G. foliifera* sometimes persisting in large masses through August or September. The heavy development of these species in the early summer is believed to be a result of the accumulation of spores shed late the previous fall. All these plants tend to grow to maturity at about the same time. The spores they shed, however, are distributed considerably in time; hence, plants that follow are also distributed and another peak of abundance does not occur the same season.

California Manufacturing Process. Dry, unbleached *Gelidium* is soaked and washed in fresh water for about 12 hours. It is then transferred to steam pressure cookers to which the dilute agar solution from the third cooking of a previous batch is added. The ratio of water is about 1 gallon per dry pound of *Gelidium.* Cooking is done at 15 pounds pressure for about 6 hours. The seaweed residue is saved and cooked twice more, usually 8 and 12 hours, respectively. The agar solution and residue are separated by a filter screen. The crude agar solution is pumped into a storage tank where it is kept hot while diatomaceous earth filter aid is added and the solution agitated. As it is forced through a filter press, it becomes a clear, amber liquid. It is next cooled and gelled for about 24 hours in open tubs. The firm agar gel is fed to a chopper from which small pieces drop into 100-pound capacity ice cans that are placed in a cold room at 14° F (– 10° C) for 2 days. The frozen agar gel is thawed in tanks at about 50° F (10° C) and then goes to a "dewaterer" in which it passes over a screen beneath which a vacuum is applied. Excess water is drawn off the agar flakes, which are retained on the screen and are conveyed to a vertical stack drier through which air at 215° F (101.7° C) is forced. As the wet agar flakes, which at first contain about 90 per cent moisture, become drier and lighter they eventually are blown to the top of the stack and into the downpipe. At this point they contain about 35 per cent moisture. Bleaching is then done by treatment with a 1.0 per cent solution of sodium hypochlorite at room temperature, after which excess hypochlorite is reduced by treatment with a sodium sulfite solution. The agar flakes are again sent through the stack driers and the moisture is reduced to 20 per cent. The flakes are granulated in a hammer mill and are ready for market.

North Carolina Manufacturing Process. Dry, unbleached *Gracilaria confervoides,* or *G. foliifera* (the two are usually kept separate), is placed in wooden tanks with perforated steam pipes in the bottom. The seaweed is covered with water

and heated to the boiling point for a brief period in order to remove salts and pigments. The water is then discarded and the wet seaweed conveyed to a cooker where new water is added in the proportion of about 20:1 of dry seaweed. It is cooked for about an hour by perforated steam coils in a tank with an opening at the top. The contents of the cooker are conducted to a shaker screen, the agar solution to a heated storage tank, and the seaweed residue to another cooker. Filter aid is added in the storage tank and the solution goes through a filter press and into 300-pound ice cans. The cans are stood in cold water to cool and gel the solution, then placed in brine and frozen. When the seaweed residue is cooked a second time, the insoluble portion (mostly cellulose) is so finely divided that the ultimate residue is retained by the filter press.

Blocks of frozen agar gel are removed from the cans and slid down an incline to a large wheel, equipped with angular blades. As the wheel rotates, the ice is shaven. Ice flakes are conveyed to a tunnel drier where they are spread evenly to a depth of about 2 inches on screen-bottom trays. The trays are conveyed by small carts through the drying tunnel against a current of hot air. The ice melts within the first 30 feet; dry agar sheets come out of the tunnel in a grinding room. The dry, brittle sheets are hammer-milled and ready for market. Some agar is finely pulverized for special purposes.

The Agar Industry in Other Countries. *Russia.* Production of agar from *Ahnfeltia plicata* (Hudson) Fries, and of an agaroid from *Phyllophora rubens* (L.) Greville, was undertaken in Russia about 1930. The Russians learned of agar possibilities from the Japanese of Karafuto, the southern part of Sakhalin Island, located north of Japan, where large quantities of *Ahnfeltia* are found. The Sea of Japan near Vladivostok, as well as the Archangel vicinity of the White Sea, furnishes *Ahnfeltia* in quantity. *Phyllophora* agaroid, produced in greater quantity than *Ahnfeltia* agar, is obtained from raw material collected in the Black Sea near Odessa.

The process used to produce agar from *Ahnfeltia* in Russia differs in some respects from that in the United States and Japan. It would appear that the *Ahnfeltia* extractive is very easily affected by the procedure used in its preparation. Dry raw material is first soaked in lime water for 3 days. It is then cooked for 10 hours in the ratio of 1 part dry seaweed to each 15 parts, by weight, of a solution of 5 per cent calcium oxide. Extraction with the pH at neutrality results in an agaroid (low gel strength agar), while the extractive will fail to gel entirely if the pH is on the acid side. Since pressure cooking is also harmful to the gel strength, open boiling is preferred. The presence of neutral salts tends to reduce the quality of the agar by increasing the ash content, although they do not affect the yield. Decolorization of the agar is effected by the addition of activated carbon just before filtration. Slow freezing is best as the ice crystals formed tend to be larger; melting is done at 35.6 to 41° F to keep reabsorption of the water to a minimum. The wet agar flakes are further washed in large quantities of cold water. According to Kizevetter (1941), *Ahnfeltia* agar "equals the high grade agar made abroad, and in some respects excels it."

Russian scientists have published many reports (Dokan, Elin, Kizevetter, Koryakin, Zhelezkov) on the technology, manufacturing processes, chemical nature, physical properties, and various uses of Russian agar and agaroid.

New Zealand. In 1939 government laboratories in New Zealand began to investigate the suitability of domestic seaweed as a source of agar. Four species, *Pterocladia lucida* (R. Br.) J. Agardh, *P. capillacea* (Gmelin) Bornet and Thuret, *Gelidium caulacantheum* J. Agardh, and *Gracilaria confervoides,* have been investigated (Moore, 1944). The first mentioned species is the principal source because of its suitability and abundance. The properties of *Pterocladia* agar are similar to those of its close relative, *Gelidium,* and it is satisfactory for bacteriological culture media and other usual agar uses. There is some disagreement in the literature as to the superiority or inferiority of its gel strength in comparison with Japanese agar of commerce (No. 1 grade).

From 1942 through 1949 over 100 tons, dry weight, of *Pterocladia* were collected annually in New Zealand. Most of this raw material came from two areas: the west coast of North Auckland and the Bay of Plenty. Most of the collecting is done by the Maoris and most of the seaweed obtained is driftweed that would decay along the shore if not gathered. Summer and fall are the principal seasons. Collectors receive about one shilling per dry pound for good quality *Pterocladia.* Since the yield of agar is about 25 per cent of the dry weight of the raw material, agar production in New Zealand from 1942 through 1949 may have averaged up to 25 tons per year, based on the collection data just given.

Australia. Gracilaria confervoides has been used as a source of agar in Australia since 1942. In 1945 production was about 2 tons per month (Wood, 1946), but known supplies of raw material were adequate for a production goal of 100 tons per year.

Australian *Gracilaria* agar is said to have a lower gel strength in the lower concentrations and a higher gel strength in higher concentrations (1.5 per cent and above) than Japanese agar. Since Japanese agar varies widely, the comparison is a rough one. Australian agar is more elastic, usually gelling at a higher temperature, 122–131° F (50–55° C), is more transparent, and exhibits greater syneresis than *Gelidium* agar. It is similar to North Carolina *Gracilaria* agar in these characteristics and is more suitable for industrial and food uses than for bacteriological media.

Australia's raw material is found along the east coast, especially in Moreton Bay, Botany Bay, Middle Harbour, and Lake Woolaweyah on the Clarence River. The plants grow from very shallow water to a depth of 20 feet and are attached to stones and shells, often reaching a length of 2 feet or more. Harvesting is done from the seaweed beds and driftweed is gathered along the shore after storms. 7 pounds of fresh seaweed are required (as compared to 10 or more in North Carolina) for 1 pound of dry seaweed. The yield of such material is about 33 per cent if two extractions are made (Makaroff, 1946), nearly double the commercial yield of the North Carolina and Florida species. Australian raw material cost 5 to 10 cents per pound in 1945 and 1946.

Australia's production process is similar to that used in the United States. About 96 pounds of water are used for each 4 pounds of dry seaweed. Centrifuges are used to separate the agar solution and the seaweed residue; the resulting solution, after filtration, is concentrated by evaporation under vacuum. Thus, a higher concentration is frozen. The following table shows how agar was used in Australia in 1938.

TABLE 18. USES OF AGAR IN AUSTRALIA, 1938.*

	Pounds
Meat preserving	99,350
Confectionery	33,235
Spices and condiments	24,416
Chemical, medical, etc.	1,459
Jams and vegetable pastes	1,459
Aerated waters and cordials	336
	160,255

South Africa. During World War II several species of seaweeds were investigated as possible agar sources in the Union of South Africa. Although *Gelidium cartilagineum* is present, *Gracilaria confervoides* was the principal species utilized because of its greater abundance and ease of collection. Agar from *Gracilaria,* collected in a certain area in South Africa, has the same value as *Gelidium* agar for use in culture media because it gels at 35° to 37° C (95° to 98° F) and has a high gel strength and a relatively low viscosity in liquid condition. *Gracilaria* from other areas in South Africa yields agar similar in properties to that from Australian and North Carolina *Gracilaria* (i.e., with a higher temperature of gelation). South Africa's agar production of about 25 tons per year through 1949 is based upon *Gracilaria* raw material having these favorable properties. Plans for 1950 called for a doubling of production with full utilization of the freezing capacity of South Africa's factory, Vitamin Oils Limited, located at Cape Town.†

Although *Gelidium pristoides* is abundant in South Africa, it produces an extractive of somewhat lower gel strength than agar of commerce. Agaroids have been prepared on a small scale from *Suhria vittata* and *Gigartina radula,* but an agaroid industry has not been established. *Hypnea spicifera* from the vicinity of East London, South Africa is reported to be a good source of agar (Fox and Stephens, 1943), but no information is available concerning its properties or whether it behaves in a manner similar to *H. musciformis* of the Atlantic Coast of North and South America.

Other Countries. A small agar industry of at least three factories existed in China prior to the Japanese invasion in 1937. Factories were located at Ningpo, Tsingtao, and Chefoo. Although production data were not published, Tseng (1944a) estimated their annual output at about 75,000 pounds. More recent information on these factories is not available.

Mexico, an important source of raw material for California factories during the war because of the lower cost of labor, began in about 1945 to produce agar from *Gelidium cartilagineum,* collected in Baja California. Agar production has also been reported in the Dutch East Indies and Straits Settlements.

Agars from *Pterocladia, Gracilaria, Ahnfeltia,* and other species which have come to be utilized since the beginning of World War II have been said to be superior to Japanese agar, often without indicating in what respect they are

* Wood, E. J. F., "Agar in Australia," Council for Sci. and Indus. Research, *Bulletin 203* (Div. of Fisheries Report No. 12) (1946).

† Information on South Africa's agar industry was supplied through the kindness of Dr. C. J. Molteno, Managing Director of Vitamin Oils Limited, Cape Town.

superior and without actual data of their important properties. Such claims usually arise from enthusiasm and should be regarded with skepticism unless actual physical data are presented in reproducible units. Furthermore, no phycocolloid can be said to be generally superior to another. Superiority must be stated in specific terms. Japanese agar is not superior to Irish moss gel as a stabilizer for chocolate milk; Irish moss gel (in its present forms) will never replace agar as a bacteriological culture medium.

Hypnea Agar—A New Type. *Hypnea musciformis,* which is common along the Atlantic coasts of North, Central, and South America, was first studied as a source of agar in 1942 (Humm). Preliminary results were variable and puzzling until it was realized that all solutes have a profound effect upon the physical properties of the *Hypnea* extractive. Several publications (DeLoach *et al.*, 1946; Humm and Williams, 1948) and a patent (Humm, 1948) discuss these phenomena in some detail.

There is no fundamental difference between the reaction of *Hypnea* gel to solutes and that of Irish moss gel (discussed on page 59), ordinary agar, and other phycocolloids obtained from red algae. In the case of *Hypnea,* however, the effect of solutes on physical properties is greatly magnified, with the result that these properties can be controlled over a remarkably wide range in respect to gel strength, temperature of gelation and melting, viscosity, and other characteristics. The effect of solutes on *Gelidium* and *Gracilaria* agar is so slight that detection is almost impossible, while Irish moss gel is intermediate in reaction.

The influence of various electrolytes is apparently in the order of the lyotropic series, with the cations exerting more influence than the anions. Non-electrolytes, such as sugars and alcohols, both simple and complex, are also very active as gel conditioners although studies of their relative effects have not yet been published. In equimolar concentrations there is evidence, subject to re-examination, that the alcohols are effective in the following (decreasing) order: methyl and ethyl alcohol, propylene glycol, ethyl and methyl "Cellosolve," ethylene glycol, diethylene glycol, and glycerin. The effect is apparently a result of the relative hydration of the alcohol in the presence of a solution of *Hypnea* extractive.

Hypnea musciformis is known to occur in commercial abundance in three areas: the vicinity of Beaufort, N. C., Tampa Bay, Florida, and along the coast of Brazil between Recife and Aracajú. In North Carolina, where commercial quantities were harvested in 1945 and 1946, the species is abundant usually from May through July; in the Tampa Bay area the greatest annual development occurs from December through February. In both localities plants that break loose, drift, and accumulate in certain areas constitute the stage of potential commercial value. There is considerable annual variation of abundance. In Brazil attached plants occur in quantity between the reef and the beach and apparently are not seasonal, although collecting and drying would probably be limited to the dry season, October through March.

Since the colloid obtained from *Hypnea* is soluble in cold water, drying of the seaweed must occur without excessive rain. Once dry, *Hypnea* can be washed briefly in fresh water without loss of its gelose. Carefully washed *Hypnea,* from which all but traces of salts have been removed, can be extracted in pure water at room temperature with the formation of a clear, viscous sol. If the concentration of solutes (other than the *Hypnea* colloid) is low enough, gelation does not occur,

even at relatively low temperatures. If, however, a solute is added, gelation will occur. If salt crystals are added, a ball of gel will form instantaneously around each crystal. Complete dissolution of the salt can be accomplished only by heating the solution to the melting temperature of the highest effective concentration of the salt used. Once the salt is dissolved, the temperature of gelation and melting, the gel strength, and other properties will depend upon the concentration and nature of the solute. No differences have been detected in the behavior of extractives of *Hypnea* from North Carolina, Florida, and Brazil.

The effect of various concentrations of *Hypnea* extractive with two different concentrations of KCl may be seen in Table 19.

TABLE 19. EFFECT OF VARIOUS CONCENTRATIONS OF *Hypnea* EXTRACTIVE AND OF TWO CONCENTRATIONS OF KCL ON GEL STRENGTH AND TEMPERATURE OF GELATION.

Concentration of *Hypnea* Extractive	0.2 Per Cent KCl			0.5 Per Cent KCl		
	Temp. of Gel.		Gel Strength*	Temp. of Gel.		Gel Strength*
	°F	°C		°F	°C	
0.3	93.2	34	80	116.6	47	90
0.5	93.2	34	180	118.4	48	190
0.75	95.0	35	280	118.4	48	300
1.0	96.8	36	370	120.2	49	480

The marked effect of solutes upon the viscosity of *Hypnea* extractive is shown in Fig. 5–13, in which a comparison is made with *Gelidium* agar and distilled water. Viscosity units are arbitrary numbers. It is obvious from these data that filtration of a *Hypnea* extractive solution is more readily accomplished if solutes are present; the same is true of Irish moss extractive, since it reacts to solutes in a similar, if less dramatic, manner.

The temperature of gelation and of melting, as well as the magnitude of hysteresis, of 1.0 per cent concentration of *Hypnea* agar containing various concentrations of potassium chloride is shown graphically in Fig. 5–14. The difference between the temperature of gelation and the melting temperature (hysteresis range), as determined by potassium chloride, is about 28.8° F (16° C) for all concentrations of the salt and the extractive (except, possibly, at the extremes of either variable). Other salts or solutes, however, produce different hysteresis ranges. There appears to be a positive correlation between gel strength and magnitude of hysteresis range produced by any given solute. Potassium chloride is toward the upper limit; that is, it produces a relatively high gel strength and wide range between gelation and melting.

Hypnea extractive was manufactured and marketed by the Beaufort Chemical Corporation in North Carolina during 1945 and 1946. Apparently, it has not been manufactured on a commercial scale since then (as of 1950) although it would seem to have excellent commercial possibilities by virtue of the great range of its important properties, as affected by various solutes, and the fact that these properties can be controlled independently of each other to a considerable extent. Gel strength is controlled by variation in the concentration of the extractive, with

* Gel strength data are gm per sq. cm when the weight is added at the rate of 0.5 g per second.

very little change in other properties. Temperature of gelation is controlled by concentration of the solute, with gel strength determined by which solute is employed.

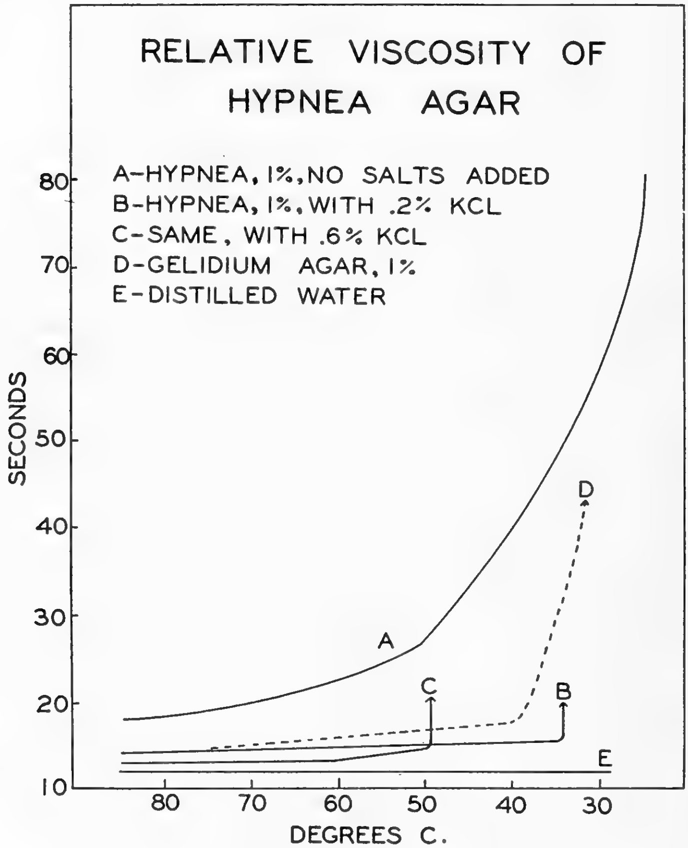


Fig. 5–13. Relative viscosity of *Hypnea* agar.

There is still much to be learned about the behavior of the *Hypnea* extractive, in particular, and about physical phenomena of phycocolloids, in general, especially those exhibited by the *Hypnea* extractive to an unusual degree.

Chemical Nature of Agar. That agar is a sulfuric acid ester of a linear galactan is generally accepted by chemists who have investigated its structure in recent years. According to Jones and Peat (1942), whose work is widely accepted, agar consists of a chain of 9 *d*-galactopyanose residues attached by 1,3 linkages, and terminated at the reducing end by one *l*-galactose residue. The great complexity of the chemical structure of agar still puzzles chemists; in fact, Percival and Thompson (1942) expressed the opinion that Jones and Peat have oversimplified the structure of agar in their conclusions. Percival and Thompson maintain that the theoretical methoxyl content of methylated agar of the formula proposed by Jones and Peat would be 42 per cent, whereas the highest observed value does not exceed 35 per cent. Barry and Dillon (1944) examined agar pre-

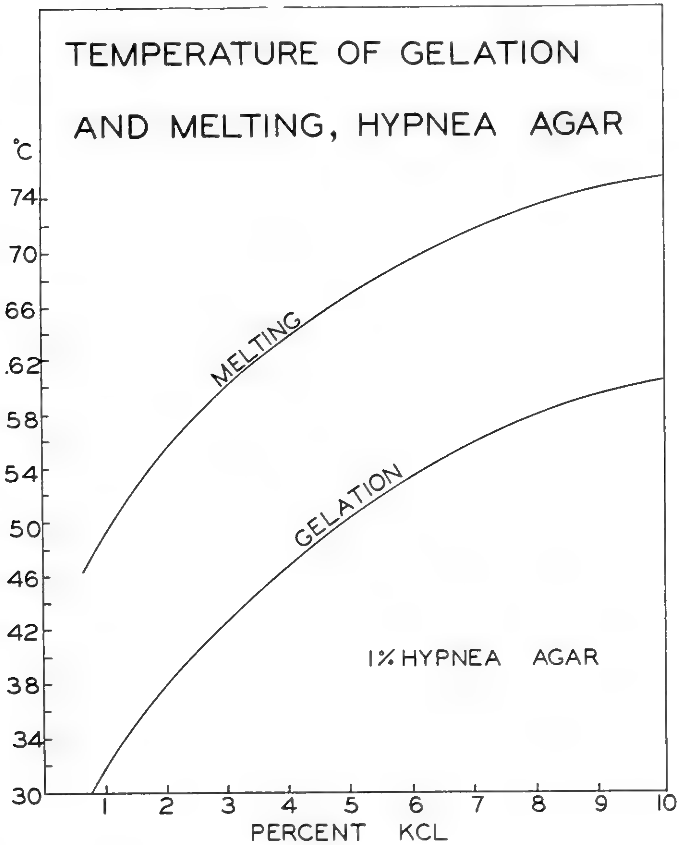


Fig. 5–14. Temperature of gelation and melting, *Hypnea* agar.

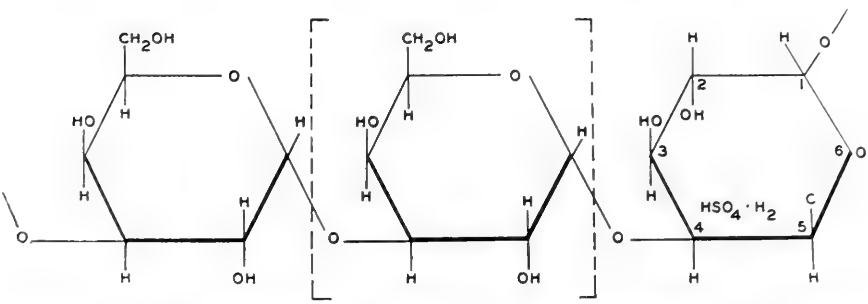


Fig. 5–15. The Jones and Peat conception of the group linkages in the structural formula for agar.

pared from *Gelidium latifolium*. After repeated purification they obtained an ash content of 2.59 per cent and a sulfur content of 0.364 per cent. This proportion of sulfur corresponds to one sulfate group to each 53 galactose units. They agreed with Percival and Thompson that agar does not contain as much as one non-reducing end group for every 140 galactose units because of the lack of detectable amounts of tetramethylgalactose in the hydrolysis products of methylated agar.

One of the difficulties that confuses chemical work on agar is the fact that very few investigators have used agar from a positively known source. Agar of commercial manufacture is worthless (harmful, actually) as a material for chemical study because it is composed of the extractives of a variety of seaweeds which are impossible, at present, to separate. This is particularly true of Japanese agar as it is made from raw material composed of intentionally mixed species of seaweeds. It should be assumed, until data indicate otherwise, that each species of seaweed produces a phycocolloid that is different chemically from all other phycocolloids. For this reason the results of Barry and Dillon (1944) may not actually conflict with the work of Jones and Peat (1942) as the two groups of investigators were using agar from different species of algae.

Chemical studies of phycocolloids, to be reliable, must begin with the dry seaweed, identified by a qualified taxonomist. Part of the material should be deposited in an herbarium for future reference. The investigators should then extract their own agar, after carefully removing all traces of other species of seaweeds that might contribute foreign phycocolloid substances. Other chemists will then be able to repeat the work and verify the results; there will be no doubt about the source of the agar under examination nor of its purity, at least with reference to contaminating phycocolloids.

More detailed information on the chemical constitution of agar and other phycocolloids is given by Tseng (1946) and Hassid (1944).

Physical Properties of Agar. Agar differs from all other phycocolloids in its unique combination of physical properties, of which two are virtually exclusive with agar: its high gel strength and its wide hysteresis range (i.e., difference between the temperature of gelation and melting). Other properties are also important, but vary with the agar source.

Agars from *Gelidium cartilagineum* of California and Mexico and from *G. amansii* (plus the usual adjunctive species) of Japan are noted for their low viscosity when in melted or liquid condition, for low syneresis (exudation of water in the gel state), and for their uniformly low temperature of gelation (34 to 40° C, 93 to 104° F). It is these properties that make *Gelidium* agar the ideal gelling agent for bacteriological culture media.

Agars from *Gracilaria confervoides* and *G. foliifera* are slightly lower in gel strength (although there are exceptions) and more viscous in liquid form, exhibit more syneresis in the gel state, and form a gel at a higher temperature than *Gelidium* agar. *Gracilaria confervoides* from South Africa is said to be exceptional because it gels at about 37° C (98° F). *Hypnea* agar is similar to that from *Gelidium* in that it possesses a relatively low viscosity (in the presence of solutes); but it resembles *Gracilaria* agar in its high degree of syneresis.

Agar from *G. confervoides* from North Carolina appears to be composed of two or more fractions that possess different temperatures of gelation (Stoloff,

1943). If cooled slowly, incipient gelation may begin as high as 63° C (145° F) in some samples with the formation of a soft gel, followed by a sudden increase in firmness as the temperature falls to 43° C (109° F), or lower. Apparently, the fraction having the high temperature of gelation comprises less than half of the total extractive and varies in its proportion with the season. Seaweed taken in early or mid-summer may lack it entirely. The two fractions may differ with respect to the metal ion involved in their chemical structure. Efforts to separate them have not been successful so far.

In Table 20 are data comparing temperature of gelation and gel strength of a variety of agars and Irish moss gel.

Swelling of Agar. Although insoluble in cold water, dry agar will absorb it in large quantities, accompanied by swelling and the evolution of heat. The amount of water absorbed at equilibrium is a variable that depends upon a variety of factors, including the original moisture content of the dry agar sample. According to the observations of Clark (1925), maximum absorption occurs if the original moisture content is 313 mg of water per g of agar. The total absorption is progressively less with less original moisture down to zero, or with greater original moisture, as shown in Fig. 5–16. Clark's work should be repeated using a variety of agars of known source. His agar was apparently of Japanese origin and probably a mixture of extractives of a dozen or more species of seaweeds.

Solutes of all kinds also affect the swelling of agar, along with their effect upon other properties as discussed in a preceding section. Dilute solutions of KCl and NaCl at concentrations between 0.001*M* and 0.01*M* cause an increase in the amount of water absorbed by agar. At concentrations above 0.1*N* electrolytes inhibit the swelling of agar in the order of the lyotropic series by competition of ions with the agar micelles for water. Non-electrolytes produce the same effect (Dokan, 1924).

Flocculation of Agar. In order to effect precipitation of agar it is necessary to remove two factors that stabilize lyophilic colloidal solutions—hydration and electric charge. The presence of minute amounts of electrolytes, always present in agar solutions with the exception of those prepared from agar purified by electrodialysis, remove the electric charge from the agar particles. Under these circumstances agar can be precipitated by pouring a melted solution into an equal volume of 95 per cent alcohol or by adding 1.0 per cent tannin. Alcohol precipitation is used to purify and dehydrate agar on a commercial scale although the process is ordinarily prohibitory in cost.

Agar can be precipitated from solution by high concentrations of electrolytes—the "salting out" phenomenon. In sufficient concentration salts remove both the electric charge and the water of hydration. Buchner and Kleijn (1927) studied the relative effect of electrolytes as agar flocculating agents and arranged the following sodium salts in the order of decreasing effectiveness: ferrocyanide, citrate, dibasic phosphate, tartrate, thiosulfate, tribasic phosphate, molybdate, formate, acetate, bromate, and chloride. They also found that certain sodium salts (chlorate, bromide, iodide, and chromate) not only failed to cause flocculation but inhibited it if they were present when the flocculating salts were added.

Uses of Agar. In general the uses of the three most important phycocolloids, agar, algin, and carrageenin, are alike in that they serve as stabilizers, emulsifiers, thickeners, vehicles or body-producers, and gelling agents. There are, however,

TABLE 20. TEMPERATURE OF GELATION AND GEL STRENGTH OF AGAR FROM VARIOUS SOURCES AND OF IRISH MOSS EXTRACTIVE.*

	Concentration Per Cent	Temp. of Gelation °F	°C	Gel Strength Grams
Carrageenin	1.0	87.8	31	15
	3.0			90
	5.0			300
Gracilaria confervoides, California	1.0	116.6	47	120
	1.5			190
Gracilaria confervoides, North Carolina †	0.5	109.4	43	113
	1.0		and	407
	1.5	138.2	59	650
Gracilaria confervoides, Australia	1.0	114.8	46	95
	1.5			167
Gracilaria confervoides, South Africa	1.0	98.6	37	187
	1.5			337
Japanese *Gelidium* † (plus other sp.)	1.0	100.4	38	70
	1.5			80
Bacto-Agar (California *Gelidium?*)	1.0	102.2	39	215
	1.5			350

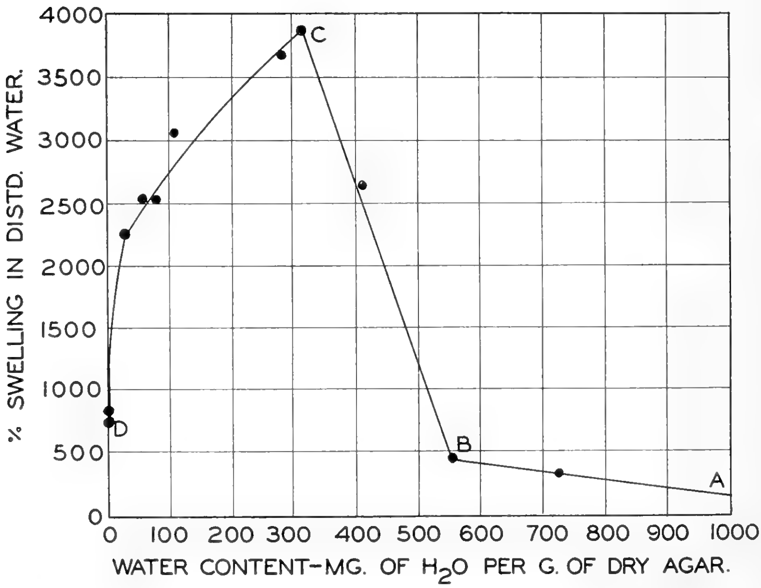


FIG. 5–16. Swelling of agar on absorption of water (from Clark, 1925).

* Stoloff, L. S., "The Agar Situation," *Fishery Market News,* 5, 1–5 (1943).

† The gel strength given for *G. confervoides* from North Carolina represents a sample of unusually high gel strength; the data on gel strength of Japanese agar apparently represent a sample of below average strength.

specific uses for each extractive for which the other two are less suitable or useless. In addition there are the overlapping uses in which two or more phycocolloids may be chosen.

The unique gel strength of agar is responsible for its great value, although the low viscosity of some agars when in melted condition is also important for certain uses. While agar is the most expensive of all the phycocolloids on a dry-weight basis, it is not necessarily the most expensive for some purposes, even where Irish moss or algin can be used. Since considerably less agar is required to obtain a gel of a given strength, the gel may cost less if made from agar instead of carrageenin.

In Foods. Among the largest users of agar in foods is the bakery industry. Agar is often added to icings to prevent their becoming sticky or adhering to wrappers during damp weather and to prevent excessive drying and brittleness under conditions of low humidity. Agar has been used as a stabilizer in chiffon pies, meringues, and pie fillings. Except where gel strength is of importance, the variety of Irish moss extractives recently developed have largely replaced agar in baked goods. Agar serves as a stabilizer in sherbets, but usually in combination with tragacanth or other gums. Both agar and carrageenin are used to control the moisture and consistency of fruit cakes.

In cream cheese of the Neufchâtel type agar and Irish moss extractive are used to reduce its tendency to exude whey at summer temperatures and to improve slicing qualities and texture.

Agar and Irish moss extractive are used in place of gelatin in many jelly candies and marshmallows, as well as fillers in various types of candy bars. Tseng (1944) estimated that over 100,000 pounds of agar are used annually in confections.

Part or all of the gel-forming substance in jelly desserts, aspic salads, puddings, fruit butters, jams or preserves may be agar or carrageenin. Mayonnaise and salad dressings are usually stabilized by one of these phycocolloids.

In the canning of pickled tongue, poultry, fish, or other soft meats agar or carrageenin is usually added to prevent the product from becoming mushy in transit. Gelatin is not entirely satisfactory as it melts at summer temperature; carrageenin melts at less than body temperature. Agar is preferred because of its high gel strength and high melting temperature. A large portion of the agar produced in Australia and New Zealand is used for this purpose.

In Pharmaceuticals. Agar is more widely known as a therapeutic agent for constipation. It is probably superior to all other intestinal "bulk producers" because of the absence of undesirable side effects. Bran, the most widely used remedy, is sometimes irritating. Since agar is indigestible (and hence has no food value), it passes through the human digestive system unchanged. If taken as a suspension of the powdered form in liquid with cereals or in baked goods, it absorbs moisture in the intestinal tract and provides the needed bulk. It has been recommended for elderly persons and children in particular. Agar taken in the gel form is less effective as it does not absorb more moisture or continue to swell.

Emulsions of agar, water, and mineral oil are only as effective as the oil constituent since the agar (or carrageenin) is too dilute to act as anything but an emulsifier. Carrageenin is less effective than agar because it is partially digested and because it absorbs so much water as to lose part of its bulk-producing effect.

Antibiotics, sulfa compounds, vitamins, and other medicaments are sometimes enclosed in an agar capsule to effect a slow release of the therapeutic agent. An agar coating or capsule remains intact longer than one composed of carrageenin or gelatin. Thus, the release of a drug to a point beyond the stomach can be delayed as with the use of lactic acid in an agar vehicle to inhibit undesirable intestinal bacteria, or to administer gentian violet for intestinal parasites. Agar particles distributed in paraffin constitute a pill coating that results in a delayed release of its contents. The slow swelling of the agar particles ultimately ruptures the coating (Miller, 1935).

Bacteriological Culture Media. Agar in bacteriological culture media serves to solidify nutrient broth so that an inoculum containing bacteria can be spread on the agar surface. Bacteria thus scattered about cannot move but will form colonies composed of cells derived from one original cell or clump of cells of the inoculum. Agar is ideal for this purpose because of its gel strength, clarity, temperature of gelation and melting, and low viscosity when melted.

Dental Impression Compounds. Agar is often the principal ingredient in a compound used by dentists to make impressions for dental crowns and plates. In impression compounds agar is present in relatively high concentration so that a very strong and somewhat elastic gel is produced. Since it gels at a temperature just above that of the human body, 38 to 40° C (100 to 104° F), the melted compound can be poured into the mold at a few degrees above its temperature of gelation, and solidification will occur with only a few degrees drop in temperature. The elasticity of the semisolid mass permits removal from undercuts without breaking or distortion. Impression compounds are used also in prosthetic work.

Laboratory Procedures. Agar gel in the form of tiny blocks has been used as a vehicle for carrying plant hormones and for applying these hormones to various parts of plants to study the effect. This procedure is known as the *Avena* test method. Agar has been used in electric pH apparatus to solidify the potassium chloride bridge. The sensitivity of dry agar to changes in humidity has been employed in the more accurate hygrographs to activate the indicator. It is said to be more accurate than human hair, a frequently used substance.

In preparing very small pieces of plants or animals for permanent microscope slides the tissue is often embedded in agar so that it will not be lost in passage through a series of solutions. Biological materials are sometimes embedded in agar to facilitate the cutting of thin sections with a freezing microtome. In chemical laboratories agar is added in very small amounts to speed the precipitation of barium sulfate.

Agar and related phycocolloids have been important as a source of information on the physical and chemical phenomena of hydrocolloids. The expanding uses and value of phycocolloids, as well as the many new types, will stimulate considerable research in this field.

Miscellaneous Uses. The addition of small quantities of agar or Irish moss extractive increases the effectiveness of insect sprays. In some cases the amount of nicotine can be reduced to one-third without loss of toxicity.

Granules of humus or peat are used as the vehicle in nitrogen-fixing bacteria for inoculating legumes. If this material is coated with agar, the moisture content is more readily controlled and there is a much slower loss in the viability of the bacteria.

Esters of agar are often used as coatings or backing on films or plates to prevent halation. These wash off in alkaline solutions.

In the manufacture of tungsten wire agar is used as a suspending agent of the graphite lubricant. Agar produced from Atlantic Coast *Gracilaria* has been found superior for this purpose.

The addition of agar granules to smoking tobacco has been found to serve as an excellent moisture-controlling agent.

Agar is also one of the most satisfactory gels for hectograph duplicators.

REFERENCES

Adams, C. M., "The Japanese Agar-Agar Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **263** (1947).

Algin Corporation of America, "Notes on Irish Moss Extracts," Mimeo. Separate (24 State St., New York 4) (1949).

Anon., "*Gigartina decipiens* from New Zealand as a Substitute for Irish Moss, with Special Reference to the Brewing Industry," *Bull. Imp. Inst.* (*London*), **41**, 163–165 (1943).

Anon., "Agar-Agar and Irish Moss (*Chondrus*)," *World Trade in Commodities*, **5**, No. 89, Pt. 2 (1947).

Aoki, K., "On the Content of Agar in *Gelidium* and Some Other Seaweeds," *Bull. Jap. Soc. Sci. Fish.*, **8**, 223–226 (1940).

Araki, C., "Chemical Studies of Agar. VI. Isolation of a New Disaccharide from Methylated Agar," *J. Chem. Soc. Japan*, **62**, 733–740 (1941).

Baker, H. C., "The Concentration of Latex by Creaming," *Trans. Inst. Rubber Indus.*, **13**, 70–82 (1937).

Barry, V. C., and Dillon, T., "A Formula for Agar," *Chem. and Indus.*, 167 (1944).

Becker, J., "Combined Congealer and Sizer (for Agar)," U. S. Pat. 1,701,744 (1929).

Becker, J., "Means and Methods of Dehydrating Flaked Agar or the Like," U. S. Pat. 1,703,654 (1929a).

Becker, J., "Dewaterer for Flaked Agar or the Like," U. S. Pat. 1,726,942 (1929b).

Becker, J., "Agar Product and Method of Producing It," U. S. Pat. 1,712,785 (1929c).

Blihovde, N., "Purification of Irish Moss," U. S. Pat. 2,231,284 (1941).

Bond, F. T., "Combination of Agar with Cheese," Brit. Pat. 1064 (1910).

Bondy, C., "Creaming of Rubber Latex," *Trans. Faraday Soc.*, **35**, 1093–1108 (1939).

Bonnot, P., "California Seaweeds," *Calif. Fish and Game*, **17**, 40–44 (1931).

Bose, J. L., Siddiqui, K., and Siddiqui, S., "Manufacture of Agar-Agar in India," *J. Sci. and Indus. Res. India*, **1**, 98–101 (1943).

Brann, A., "Wire Drawing Lubricant," U. S. Pat. 1,409,658 (1922).

Brown, C. L. M., and Lum, E. A., "Agar and Paraffin Emulsions; Extemporaneous Preparation," *Pharm. J.*, **131**, 341 (1933).

Brown, O. H., and Sweek, W. O., "Liquid Agar-Agar in Constipation," *J. Am. Med. Assoc.*, **69**, 467–468 (1917).

Buchanan, J., Percival, E. E., and Percival, E. G. V., "The Polysaccharides of Carrageen Moss (*Chondrus crispus*), Part I. The Linkage of the *d*-Galactose Residues and the Ethereal Sulfate," *J. Chem. Soc.*, 51–54 (1943).

Buchner, E. H., and Kleijn, D., "Flocculation of Agar Sols through Salt Mixtures," *Proc. Akad. Wet. Amsterdam*, **30**, 740–742 (1927).

Bungenberg-de Jong, H. G., and Gwan, O. S., "The Lyphilic Colloids. VI. The Electroviscous Effect in the Case of Two Hydrophilic Sols which do not follow Poiseuille's Law; Semen Lini and Carragheen-Schleim." *Kolloidchem. Beihefte*, **29**, 436–453 (1929).

Butler, M. R., "Some Properties of the Polysaccharide Complex Extracted from a Marine Alga, *Chondrus crispus*," *J. Biochem.*, **28**, 759–769 (1934).

Butler, M. R., "Seasonal Variations in *Chondrus crispus*," *Biochem. J.*, **30**, 1338–1344 (1936).

Butler, M. R., "Effect of Its Nitrogen Content on the Decomposition of the Polysaccharide Extract of *Chondrus crispus*," *Biol. Bull.*, **73**, 143–146 (1937).

Clark, B. L., "Studies in Swelling; the Swelling of Agar-Agar Gels as a Function of Water Content before Swelling," *J. Am. Chem. Soc.*, **47**, 1954–1958 (1925).

Cooper, W. F., and Nuttall, W. H., "Agar-Agar in Emulsion Making," *Britt. J. Photog.*, **55**, 62–67; 79–80; 109–110 (1908).

Cooper, W. F., Nuttall, W. H., and Freak, G. A., "The Use of Agar-Agar in Photography," *7th Internat. Cong. Appl. Chem.*, Sect. **9**, 62–72 (1909).

Dahlberg, A. C., "A Study of the Manufacture of Water Ices and Sherbets," *N. Y. Agr. Exp. Sta. Bull.*, **536**, 3–30 (1926).

Dahlberg, A. C., "A New Method of Manufacturing Cream Cheese of the Neufchâtel Type," *J. Dairy Sci.*, **10**, 106–116 (1927).

Dahlberg, A. C., "New Developments in Methods Used in Making Ices and Sherbets," *Ice Cream Trade J.* (April, 1930).

DeLoach, W. S., Wilton, O. C., Humm, H. J., and Wolf, F. A., "Preparation of an Agar-Like Gel from *Hypnea musciformis*," *Duke Univ. Marine Sta., Bull.* **3**, 31–42 (1946).

Dillon, T., "The Seaweed Industry and the Possibility of Its Revival," *Chem. Ind.*, **57**, 16 (1938).

Dillon, T., and O'Colla, P., "Acetolysis of Carragheen Mucilage," *Nature*, **145**, 749 (1940).

Dillon, T., and O'Tuama, T., "The Cellulose of Marine Algae," *Sci. Proc. Roy. Soc. Dublin*, **21**, 147–152 (1935).

Dokan, S., "The Effect of Electrolytes on the Solubility of Agar," *Kolloid Zeitschr.*, **34**, 155–161 (1924).

Elin, V., "Agar from *Phyllophora rubens* of the Black Sea," *Vrach. Delo (U.S.S.R.)*, **15**, 186–190 (1932).

Elsner, H., "Extracts of Carrageen and Agar-Agar," German Pat. 667,279 (1938).

Esikov, L. A., "The Working Up of Odessa Agar with Hyposulfite," *Lab. Prakt. (U.S.S.R.)*, **13**, 9–10 (1938).

Evenden, W., and Schuster, C. E., "The Use of Agar as a Matrix for Sectioning Plant Material with the Freezing Microtome," *Stain Tech.*, **13**, 145–146 (1938).

Fox, F. W., and Stephens, E., "Agar from South African Seaweeds," *South African J. Sci.*, **39**, 147–149 (1943).

Fraser, M. J., "The Irish Moss Industry of Massachusetts," *Fishery Market News*, **4**, 25–28 (1942).

Glabau, C. A., "How to Overcome Sticky Icings," *Bakers' Weekly, Pts.* I–XI (1943).

Godston, J., "Seaplant Extractives Recovered by New Techniques," *Food Industries*, **21**, 730–733 (1949).

Green, D. E., Mann, R. P., and Preble, B., "Stabilizing Chocolate Milk and Other Milk Products and Process of Making Same," U. S. Pat. 2,097,225 (1937).

Gross, P., "A New Negative Mass for Making Accurate Plastic Reproductions," *Arch. Path.*, **16**, 869–872 (1933).

Gutbier, A., and Huber, J., "Studio of Protective Colloids. XI Carragheen as Protective Colloid. I. General Colloid Chemical Investigation of the Extract of Irish Moss." *Kolloid-Zeitschr.*, **30**, 20–31 (1922).

Haas, P., and Hill, T. C., "On Carrageen, *Chondrus crispus*," *Ann. Appl. Biol.*, **7**, 352–362 (1921).

Haas, P., and Russell-Wells, B., "On the Significance of the Ash Content of Certain Marine Algae," *Biochem. J.*, **17**, 696–706 (1923).

Haas, P., and Russell-Wells, B., "Chemical and Physical Characters of Certain Mucilaginous Extracts of Seaweeds," *Pharm. J.*, **111**, 94, 127 (1923a).

Haddan, R., "Making Bread and Other Bakery Products," Brit. Pat. 525,766 (1940).
Hagerdon, M., "Manufacture of Esters of Polymerized Carbohydrates," U. S. Pat. 1,994,-608 (1935).
Hands, S., and Peat, S., "Anhydro-*l*-Galactose in Agar-Agar," *J. Soc. Chem. Ind.*, **57,** 937–938 (1938).
Hands, S., and Peat, S., "Isolation of Anhydro-*l*-Galactose Derivative from Agar-Agar," *Nature,* **142,** 797 (1938a).
Harrison, L. E., "Plastic Impression Material," U. S. Pat. 2,021,058 (1935).
Harrison, L. E., "Impression Material," U. S. Pat. 2,021,059 (1935a).
Harrison, L. E., "Impression Material and Method for Making It," U. S. Pat. 2,089,552 (Brit. Pat. 964,978) (1937).
Harvey, E. H., "The Electro-Dialysis of Agar," *Am. J. Pharm.*, **97,** 66–70 (1925).
Harvey, E. H., "A Physico-Chemical Study of U. S. P. Agar," *Ibid.*, **97,** 447–456 (1925a).
Hassid, W. Z., "Occurrence of Dulcitol in *Irideae Laminarioides*," *Plant Physiol.*, **8,** 480–482 (1933).
Hassid, W. Z., "The Isolation of a Sodium Sulfuric Acid Ester of Galactan from *Irideae Laminarioides*," *J. Am. Chem. Soc.*, **55,** 4163–4167 (1933a).
Hassid, W. Z., "The Structure of Sodium Sulfuric Acid Ester of Galactan from *Irideae Laminarioides*," *J. Am. Chem. Soc.*, **57,** 2046–2050 (1935).
Hassid, W. Z., "Carbohydrates in *Irideae Laminarioides*," *Plant Physiol.*, **11,** 461–463 (1936).
Hassid, W. Z., "The Chemistry of the Carbohydrates," *Ann. Rev. Biochem.*, **13,** 59–92 (1944).
Hauser, E. A., and Dewey, B., "Creaming of Rubber Latex," *Ind. Eng. Chem.*, **33,** 127–130 (1941).
Hitchins, A. P., and Leikind, M. C., "The Introduction of Agar-Agar into Bacteriology," *J. Bact.*, **37,** 485–493 (1939).
Hoffman, W. F., and Gortner, R. A., "The Electro-Dialysis of Agar. A Method for the Preparation of Free Agar Acid," *J. Biol. Chem.*, **65,** 371–379 (1925).
Hulbert, E. F., "Emulsions of Agar-Agar and Mineral Oil Suitable for Internal Use," U. S. Pat. 2,068,136 (1937).
Humm, H. J., "Seaweeds at Beaufort, N. C., as a Source of Agar," *Science,* **96,** 230–231 (1942).
Humm, H. J., "Agar Resources of the South Atlantic and East Gulf Coasts," *Science,* **100,** 209–212 (1944).
Humm, H. J., "Methods of Extracting Gelose from Seaweeds such as *Hypnea Musciformis* and Other Species of the Genus *Hypnea*," U. S. Pat. 2,446,091 (1948).
Humm, H. J., "Seaweed Resources of North Carolina," *In* Report, Survey of Marine Fisheries of N. C., Univ. of N. C. (1950).
Humm, H. J., and Williams, L. G., "A Study of Agar from Two Brazilian Seaweeds," *Am. J. Bot.*, **35,** 287–292 (1948).
Iredell, C. V., "Lubricant for Wire Drawing," U. S. Pat. 1,724,134 (1929).
Isaac, W. E., "Seaweeds of Possible Economic Importance in the Union of South Africa," *J. So. African Bot.*, **8,** 225–236 (1942).
Isaac, W. E., Finlayson, M. H., and Simon, M. G., "Agar from South African Seaweeds," *Nature,* **151,** 532 (1943).
Jensen, H. L., "Bacteriological Use of Agar Made from Australian Seaweed," *Aust. J. Sec.*, **5,** **161** (1943).
Jones, W. G. M., and Peat, S., "Constitution of Agar," *Chem. Soc. J.*, **1942,** 225–231 (1942).
Kawai, T., "Films from Kanten or Agar-Agar," Brit. Pat. 343,702 (1930).
Kizevetter, I. V., "Agar-Agar from Red Alga *Ahnfeltia plicata*," *Bul. Pacific Scientific Institute of Fisheries and Oceanography,* **13,** 1–133 (1937).

Kizevetter, I. V., "The Maritime Weed *Ahnfeltia plicata* as Raw Material for the Agar Industry," *J. Appl. Chem.* (*U.S.S.R.*), **14**, 250–255 (1941).

Koryakin, A. I., "The Preparation of Culture Media from 4 Kinds of Odessa Agar," *Lab. Prakt.* (*U.S.S.R.*), **1**, 8–9 (1939).

Krim-Ko Company, "Carragar, New Solidifying Agent for Bacteriological and Mycological Media," Mimeo. separate, Krim-Ko Co., Scituate, Mass. (1943).

Krim-Ko Company, "'Krim-Ko' Stabilizer Products and Their Uses," *Mimeographed Brochure.* (63 David St., New Bedford, Mass.) (1948).

Lee, C. F., and Stoloff, L. S., "Studies on Gum Extracts from *Gracilaria Confervoides* (North Carolina)," U. S. Fish and Wildlife Service, *Special Scientific Rept.*, No. **37** (1946).

Leon, J. H., "Improving Irish Moss Gel," French Pat. 680,188 (1929).

Lund, A. A., "Product from Sea Moss Suitable for Use in Stabilizing and Jelling Foods, etc.," U. S. Pat. 2,337,562 (1943).

Lunde, G., and Lie, J., "Vitamin C in Seaweed," *Zeitschr. Physiol. Chemie,* **254**, 227–240 (1938).

MacAdie, W., "Decoction of Irish Moss," *Pharm. J.*, **149**, 116 (1942).

McGavack, J., "Methods of Treating Latex," U. S. Pat. 1,647,805 (1927).

McGavack, J., "Improvement in or Relating to Creaming of Latex," Brit. Pat. 417,162 (1934).

McGavack, J., "Creaming of Latex," U. S. Pat. 1,989,241 (1935).

Mackinnon, H. D., "Agar: A Colloid of Importance Takes Its Place as a Food Adjunct," *Food Industries,* **2**, 123–127 (1930).

Madge, M. A., "The Use of Agar in Embedding Small or Slender Objects," *Am. Bot.*, **50**, 677 (1936).

Maine (State of), "The Maine Sea Moss Industry," *A Bulletin of the Department of Sea and Shore Fisheries,* Mimeographed (1948).

Makaroff, A., "Australia's Agar Industry," *Food Industries,* **18**, No. 10, 101–103 (1946).

Malm, C. J., and Emerson, J., "Esters of Agar," U. S. Pat. 2,211,338 (1941).

Marquardt, J. C., "Making Cream Cheese to a Formula," *Food Industries,* **2**, 76–79 (1930).

Matsuoka, C., "A Process for Making Agar-Agar," U. S. Pat. 1,399,359 (1921).

Matsuoka, C., "Agar-Agar Composition and Method of Producing the Same," U. S. Pat. 1,453,848 (1923).

Merck, E., "Purification of Agar," German Pat. 272,145 (1913).

Mertle, J. S., "Colloids in Photomechanics," *Graphic Arts Monthly,* **9**, No. 10, 32, 34, 36 (1937).

Miller, G. C., "Chemical Process," U. S. Pat. 1,605,130 (1926).

Miller, G. C., "Medical Compound," Canadian Pat. 277,180 (1928).

Miller, G. C., "Agar Compound (Medicinal)," U. S. Pat. 1,742,409 (1930).

Miller, G. C., "Coating for Medical Compound," U. S. Pat. 2,011,587 (1935).

Miller, G. C., Kurka, J. F., and Chase, L. B., "Agar Medical Compound," U. S. Pat. 1,688,053 (1928).

Moore, L. B., "Agar-Agar Production in New Zealand," *Bull. Imp. Inst.* (*Gr. Brit.*), **39**, 355–358 (1941).

Moore, L. B., "The Economic Importance of Seaweeds," *New Zealand Dept. Sci. Indus. Res. Bull.*, **85** (1941a).

Moore, L. B., "War-Time Interest in Marine Algae," *Chronica Botanica,* **7**, 406–409 (1943).

Moore, L. B., "New Zealand Seaweed for Agar-Manufacture," *N. Z. J. Sci. and Tech.*, **25**, 183–209 (1944).

Moore, L. B., "New Zealand Seaweed for Agar-Manufacture. Review of Supplies," *N. Z. J. Sci. and Tech.*, **25**, 311–317 (1946).

Morse, J. L., "Agar-Agar in the Treatment of Constipation of Childhood," *J. Am. Med. Assoc.*, **55**, 934–935 (1910).

Needler, A. W. H., "Irish Moss Industry of the Maritime Provinces," Fisheries Research Board of Canada, *General Series Circ. 10, Atlantic Biol. Sta.* (1947).

Nishio, K., "Concentrated Food Composition and Method of Making the Same," U. S. Pat. 1,497,193 (1924).

Nitardy, F. W., "Medicinal Composition Containing Agar," U. S. Pat. 1,799,804 (1931).

Nitardy, F. W., Berg, F. F., and Geirgi, P., "Medical Agar-Petrolatum Compositions," U. S. Pat. 1,913,561 (1931).

Norris, E. R., Simeon, M. K., and Williams, H. B., "Vitamin B and Vitamin C Content of Marine Algae," *J. Nutrition*, **13**, 425–433 (1937).

Okamura, K., "Uses of Algae in Japan," *Proc. Fifth Pacific Sci. Cong.*, **4**, 3153–3161 (1933).

Oki, S., and Imo'o, K., "Powdered Agar-Agar," Jap. Pat. 99,061 (1933).

Paffenbarger, G. C., "Hydrocolloidal (Dental) Impression Materials: Physical Properties and Specifications," *J. Am. Dental Assoc.*, **27**, 373–388 (1940).

Paffenbarger, G. C., "Current Developments in Dental (Impression) Materials," *N. Y. J. Dent.*, **13**, 57–63 (1943).

Parson, F. B., "Liquid Paraffin, Agar, and Bassorin in Constipation," *Pharm. J.*, **129**, 112–113 (1932).

Percival, E. G. V., "The Chemical Constitution of Agar-Agar," *Pharm. J.*, **142**, 189 (1939).

Percival, E. G. V., Somerville, J. C., and Forbes, I. A., "Isolation of an Anhydro-Sugar Derivative from Agar," *Nature*, **142**, 797–798 (1938).

Percival, E. G. V., and Thompson, T. G. H., "Studies on Agar-Agar. Pt. IV," *J. Chem. Soc.*, 750–755 (1942).

Pfister, A., "Purification of Irish Moss," U. S. Pat. 2,231,283 (1941).

Pirie, N. W., "Some Chemical Methods for the Detection and Rough Estimation of Agar in Biological Materials," *Brit. J. Exper. Path.*, **17**, 269–278 (1936).

Poller, A., "An Improved Material for Moulding Articles of All Kinds, More Particularly Parts of Living Bodies," Brit. Pat. 252,112 (1925).

Poller, A., "Plastic Hydrocolloid Composition," U. S. Pat. 1,672,776 (1928).

Popovich, B. I., "Purification of Agar-Agar," Russ. Pat. 44,289 (1939).

Rankin, C., "The Use of Irish Moss as Copper Finings," *J. Inst. Brew.*, **35**, 287–291 (1929).

Reedman, R. J., and Buckley, L., "Investigations on the Use of Irish Moss in Canning of Meat," *Canadian J. Res.*, **21**, 348–357 (1943).

Riebensahm, W., "Process of Manufacturing Limpid Solutions of Agar-Agar and Product of Same," U. S. Pat. No. 784,349 (1905).

Robertson, G. R., "Agar Industry in California," *Ind. Eng. Chem.*, **22**, 1074–1077 (1930).

Rullman, W. A., "Cereal Preparation," U. S. Pat. 1,163,175 (1915).

Russell-Wells, B., "On Carrageen (*Chondrus crispus*). III. The Constituents of the Cell Wall," *Biochem. J.*, **16**, 578–586 (1922).

Sandholzer, L. A., et al., "Studies of Bacteriological Agar II," *Bacteriological Studies* (1949).

Schoenbeck, F., and Czapp, E., "Plastic Material from Vegetable Glues," U. S. Pat. 2,312,446 (1943).

Schofield, M., "Utilising the Seaweed Harvest," *Discovery*, **10**, No. 9, 273–277 (1949).

Schulz, R. G., "Preparation of Jelly-Forming Organic Substances," U. S. Pat. 2,019,363 (1935).

Selzer, W., "Stabilizing Material. (Irish Moss)," U. S. Pat. 2,011,594 (1935).

Sharp, S. S., "Agar-Agar a New Activator for Nicotine Sprays," *J. Econ. Entomol.*, **32**, 394–395 (1939).

Sher, H., "Vegetable Food Product and Dessert Preparation," U. S. Pat. 1,974,474 (1934).

Skinner, E. W., and Kern, W. R., "Colloid Impression Materials," *J. Am. Dent. Assoc.*, **25**, 578–584 (1938).

Smith, G. M., "Cryptogamic Botany," New York, McGraw-Hill Book Co., 1938.

Smith, H. M., "The Seaweed Industries of Japan," U. S. Bureau of Fisheries *Bull.*, **24**, 135–165 (1905).

Smith, H. M., "Utilization of Seaweeds in the United States," *ibid.*, **24**, 167–181 (1905a).

Smuskovich, I. E., "Agar-Agar," Russ. Pat. 56,068 (1939).

Spaulding, M. F., "Comparative Efficiencies of Humus and Agar as Carriers for Legume Bacteria of Soy Beans and Peanuts," *Soil Sci. Soc. Am. Proc.*, **5**, 259–261 (1940).

Stanford, E. C. C., "On the Economic Applications of Seaweed," *J. Soc. Arts*, **32**, 717–732 (1884).

Stangenberg, J. W. H., "Plastic Hydrocolloid Composition and Method of Making," U. S. Pat. 2,165,680 (1939).

Steinitzer, F., "Process of Purifying Agar," German Pat. 269,088 (1912).

Stoloff, L. S., "The Agar Situation," *Fishery Market News*, **5**, 1–5 (1943).

Stoloff, L. S., "Syneresis of Agar Gels," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **307** (1948).

Stoloff, L. S., "Strength Measurement of Agar Gels," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **306** (1948a).

Stoloff, L. S., "Routine Method for Testing Krim-Ko Gel," Mimeo. separate, New Bedford, Mass., Krim-Ko Corp., 1948b.

Stoloff, L. S., "Irish Moss—From an Art to an Industry," *Econ. Bot.*, **3**, 428–435 (1949).

Stoloff, L. S., "Irish Moss Extractive Solutions by Acidulation," Mimeo. separate, New Bedford, Mass., Krim-Ko Corp., 1950.

Stoloff, L. S., and Lee, C. F., "Agar and Other Seaweed Gums: A Summary of Data on Chemical and Physical Properties, U. S. Fish and Wildlife Service, *Fishery Leaflet*, **173** (1946).

Stoloff, L. S., and Lee, C. F., "Studies of Bacteriological Agars. I. Physical and Chemical Properties," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **335** (1949).

Tokareva, E. P., "Purification of Technical Agar," *Konservnaya Prom.*, **3**, 36–37 (1936).

Tschudy, R. H., and Sargent, M. C., "Agar-Bearing Seaweeds at La Jolla, California," *Science*, **97**, 89–90 (1943).

Tseng, C. K., "*Gloiopeltis* and the Other Economic Seaweeds of Amoy, China," *Lingnan Sci. J.*, **12**, 43–63 (1933).

Tseng, C. K., "Marine Products of Kiachow Bay," *Science* (*Sci. Soc. of China*), **17**, 1931–1947 (1933a).

Tseng, C. K., "Economic Seaweeds of Kwantung Province, China," *Lingnan Sci. J.*, **14**, 93–104 (1935).

Tseng, C. K., "Agar: A Valuable Seaweed Product," *Sci. Monthly*, **58**, 24–32 (1944).

Tseng, C. K., "Utilization of Seaweeds," *Sci. Monthly*, **59**, 37–46 (1944a).

Tseng, C. K., "America's Agar Industry," *Food Industry*, **17**, No. 1, 80–81, 192; No. 2, 84–85, 174, 176, 178; No. 3, 80–81, 178, 180 (1945).

Tseng, C. K., "Phycocolloids: Useful Seaweed Polysaccharides," Alexander, J., "Colloid Chemistry: Theoretical and Applied," **6**, 629–734, New York, Reinhold Publishing Corp., 1946.

Tseng, C. K., "Seaweed Products and Their Uses in America," *J. N. Y. Bot. Garden*, **47**, 1–39 (1946a).

Tseng, C. K., "Seaweed Resources of North America and Their Utilization," *Econ. Bot.*, **1**, 69–97 (1947).

Tsuboi, S., "Agar-Agar as an Additional Agent in the Electroplating of Lead," *J. Chem. Ind. Japan*, **21**, 648–666 (1918).

Utouki, K., "Agar-Agar," Jap. Pat. 42,126 (1922).

van Rossem, W. J., "Method of Controlling the Physical Dimensions of Molded Hydrocolloid Bodies," U. S. Pat. 2,246,822 (1941).

van Rossem, W. J., "Hydrocolloid Molding Composition and Material for Use Therein," U. S. Pat. 2,265,118 (1941a).

von Brandt, H., "High Concentration of Agar-Agar Gel," U. S. Pat. 2,042,917 (1936).

Walker, A. W., and Day, A. A., "Extracts from Irish Moss as a Substitute for Agar in Bacteriological Culture Media," *Food Research*, **8**, 435–443 (1943).

War Production Board, "General Preference Order M–96; To Conserve the Supply and Direct the Distribution of Agar," *Title 32, Nat. Defense, Chapt. IX, W.P.B., Subchapt. B, Div. of Industry Operations*, Pt. 1102 (1942).

Warren, L. E., "Examination of Some Liquid Petrolatum-Agar Emulsions," *J. Am. Med. Assoc.*, **84**, 1682–1683 (1925).

Washburn, R. M., "Fruit Juice Powder and Stabilizing Thereof," U. S. Pat. 1,844,707 (1932).

Williams, R. H., "Seaweed Utilization in South Florida," *Proc. Fla. Acad. Sci.*, **9**, 161–170 (1944).

Williams, R. H., "Florida Seaweeds and Their Commercial Use," *Fla. State Bd. of Education*, Educ. Series No. 7 (1950).

Wilson, E., "Dulsing at Dark Harbor," *Nature Mag.*, **36**, 127–128 (1943).

Wilson, L. A., "Medicine," U. S. Pat. 1,784,324 (1930).

Wing, W. T., "Decoction of Irish Moss," *Pharm. J.*, **149**, 103 (1942).

Wood, E. J. F., "Agar-Agar a New Potential Industry in Australia," *J. Coun. Sci. and Indus. Res. Australia*, **14**, 221 (1941).

Wood, E. J. F., "The Harvesting of *Gracilaria Confervoides* for Agar-Agar," *ibid.*, **14**, 315–316 (1941a).

Wood, E. J. F., "Agar-Agar Manufacture," *ibid.*, **15**, 295–299 (1942).

Wood, E. J. F., "Agar in Australia," *Council for Sci. and Indus. Research Bull. 203* (Div. of Fisheries Report No. 12) (1946).

Zhelezkov, P. S., "The Relations between the Freezing Out and the Concentration of the Gels of Agar-Agar," *Colloid J. (U.S.S.R.)*, **5**, 409–410 (1939a).

Zhelezkov, P. S., "Effects of Sugars, Alcohols, Anions, Organic Acids, and pH on the Rigidity of Agar Gels," *Colloid J. (U.S.S.R.)*, **5**, 733–740 (1939b).

Zhelezkov, P. S., "Effects of Salts and pH on the Freezing Out of Agar," *Colloid J. (U.S.S.R.)*, **6**, 403–407 (1940).

CHAPTER 6

The Brown Algae—Algin from Kelps and Fucoids

Most of the masses of seaweed along the shores of North America and Europe are brown algae. The two principal genera are *Laminaria,* which is usually found in deep water, and *Fucus,* which commonly grows on the rocks between the tidal levels.

Formerly, great quantities of *Laminaria* and giant kelp (chiefly *Macrocystis pyrifera*) were burned and the ashes used for the production of iodine, iodides, and potassium salts. Since this industry is no longer of considerable commercial importance, it will not be described in this chapter; however, a detailed description of methods formerly used may be found in the first edition of this book.

After the kelp-burning industry ceased to exist, the principal commercial use of brown algae has been the manufacture of algin and its derivatives (i.e., its salts and esters). In 1883 this industry was started by Stanford (1883, 1884, 1886), who noticed that a viscous liquid formed in sacks contained in the fronds of certain *Laminaria* when they were soaked in fresh water. When this liquid was expressed and evaporated, a substance resembling albumen resulted; it was only slightly soluble in pure water but easily soluble in water containing a small amount of sodium or potassium hydroxide or carbonate. Stanford named this colloidal substance, which was soluble in dilute soda solution, algin or alginic acid. He recognized its commercial possibilities and carried out extensive experiments to determine the properties and possible uses of alginic acid and alginates. Later he manufactured it on a commercial scale in Scotland. The factory was not commercially successful at that time, but more recently the manufacture of algin has become an important industry, both in the United Kingdom and the United States.

The Chemical and Physical Properties of Algin and Sodium Alginate

Alginic acid, or algin, is an organic acid which occurs in large quantities in many seaweeds having the composition of 42.0 per cent carbon, 4.5 per cent hydrogen, and 53.4 per cent oxygen. It is very slightly soluble in cold water, slightly soluble in boiling water, and insoluble in alcohol, ether, and glycerol. Moist alginic acid is capable of absorbing 10 to 20 times its weight of water. When moist, it is readily soluble in dilute alkali; but, when dried, it becomes very hard and horny and resistant to solvents. Dried alginic acid can be turned on a lathe.

If a solution of sodium alginate is acidified with a strong mineral acid, it liberates free alginic acid, which, being insoluble in water, precipitates as a white gelatinous mass. Sodium alginate in solution is coagulated by ethyl and methyl alcohol and acetone.

Sodium alginate solutions are transposed by solutions of the salts of the following metals, insoluble alginates being formed: cobalt, copper, platinum, nickel,

silver, bismuth, antimony, zinc, cadmium, aluminum, chromium, uranium, barium, calcium, and strontium. Insoluble alginates are also formed by solutions of the following salts: stannous and stannic chloride, mercurous and mercuric nitrate, ferrous sulfate, ferric chloride, and lead acetate. A solution of sodium alginate is not precipitated nor coagulated by alkalies and salts of alkalies, including: lithium, alkaline silicates, and potassium bichromate; sodium stannate, succinate, biborate, and tungstate; magnesium and manganese salts, starch, glycerol, sucrose, amyl alcohol; boric, acetic, carbolic, tannic, butyric, benzoic, gallic, pyrogallic, arsenious, and succinic acids; mercuric iodide and chloride; and bromine, iodine, and chlorine. Insoluble algin derivatives of metal (e.g., copper) form complexes with ammonia and consequently can be dissolved in an ammoniacal solution. Sodium alginate solutions are not coagulated by heat nor gelled by cooling. They can easily be distinguished from gelatin since they are not precipitated by tannin.

Table 21. Metallic Alginates.

Metal	Salt Used	Character of Precipitate	
Soluble Alginates * † (Precipitated by Alcohol)			
Li	Li (acetate)	Silver white	Gelatinous, transparent
Na	NaOH	White	"Stringy", brittle when dry
Mg	Mg (acetate)	do	Transparent, gelatinous
NH_4	NH_4OH	Light yellow	Light, gelatinous
K		Transparent	Light, fluffy
Insoluble Alginates (Precipitated from Acetic Acid Solution)			
Al	$AlCl_3$	White	Gelatinous, brittle when dry, brown color
Ca	$CaCl_2$	do	Gelatinous, glossy when dry
Cr	$Cr(NO_3)_3$	Light blue	Heavy, nongelatinous
Mn	$Mn(C_2H_3O_2)_2$	Light red	Gelatinous, good gloss to paper when dry
Fe^{++}	$FeSO_4.7H_2O$	Light brown	Gelatinous, brittle when dry
Fe^{+++}	$FeCl_3$	Brown	Gelatinous
Co	$Co(NO_3)_2$	Reddish	Gelatinous, good gloss to paper when dry
Ni	$NiCl_2$	Light green	Gelatinous
Cu	$CuSO_4$	do	do
Zn	$ZnSO_4$	Colorless	Gelatinous, silvery gloss to paper when dry
Sr	$Sr(NO_3)_2$	Light brown	Heavy, gelatinous, transparent when dry
Ag	$AgNO_3$	White	Gelatinous, becomes dark red when dry
Cd	$Cd(NO_3)_2$	Colorless	do
Sn^{++}	$SnCl_2H_2O$	White	Thick, gelatinous
Sn^{++++}	$SnCl_4$	do	do
Ba	$BaCl_2$	do	Gelatinous, good gloss to paper when dry
Pt	$PtCl_4$	Light brown	Gelatinous
Au	$AuCl_3$	Red	do
Hg^+	$Hg_2(NO_3)_2$	White	Dense, white, gelatinous
Pb	$Pb(C_2H_3O_2)_2$	Colorless	Gelatinous, like isinglass when dry
Bi	$Bi(NO_3)_2$	White	Gelatinous
U	$U(SO_4)_2.4H_2O$	Yellow	Thick, gelatinous

* All the soluble alginates give more or less gloss to paper.

† Hoagland, D. R., "Organic Constituents of Pacific Coast Kelps," *J. Agr. Res.*, 4, 39–58 (1915).

TABLE 22. ALGIN CONTENT OF VARIOUS ALGAE.*
(Water-free basis)

Alga		Algin Per Cent
Macrocystis pyrifera, leaves	Average, 20 samples	16.2
Macrocystis pyrifera, stems	Average, 20 samples	18.2
Nereocystis leutkeana, leaves	Average, 4 samples	14.4
Nereocystis leutkeana, stems	Average, 4 samples	13.6
Pelagophycus porra, leaves	Average, 2 samples	16.1
Pelagophycus porra, stems	Average, 2 samples	15.9
Egregia laevigata, entire plant	Average, 2 samples	18.7
Egregia menziezii, entire plant	Average, 3 samples	19.1
Laminaria andersonii, entire plant		22.8
Iridoea sp., entire plant		1.0
Laminaria digitata, stem		33.3
Laminaria digitata, leaves		31.9
Laminaria stenophylla, stem		39.2
Laminaria stenophylla, leaves		40.1

According to chemists who have studied its structure, alginic acid is a hydrophilic colloidal polymer of anhydro -β-*d*-mannuronic acid (Schoeffel and Link 1933; Niemann and Link 1933; Nelson and Cretcher 1929) with the empirical formula $(C_6H_8O_6)_n$. Alginic acid reacts with carbonates to produce carbon dioxide and may be titrated with an alkali to an end point by using a phenolphthalein indicator. It does not give the reducing sugar reaction with Fehling's solution, but, if dried at 212° F (100° C) or boiled with water or dilute acid, it may be converted into reducing substances. It has an optical rotation of approximately

$$\left[\alpha\right]_{D}^{20} = -133°.$$

Harvesting of Seaweed for Algin Manufacture

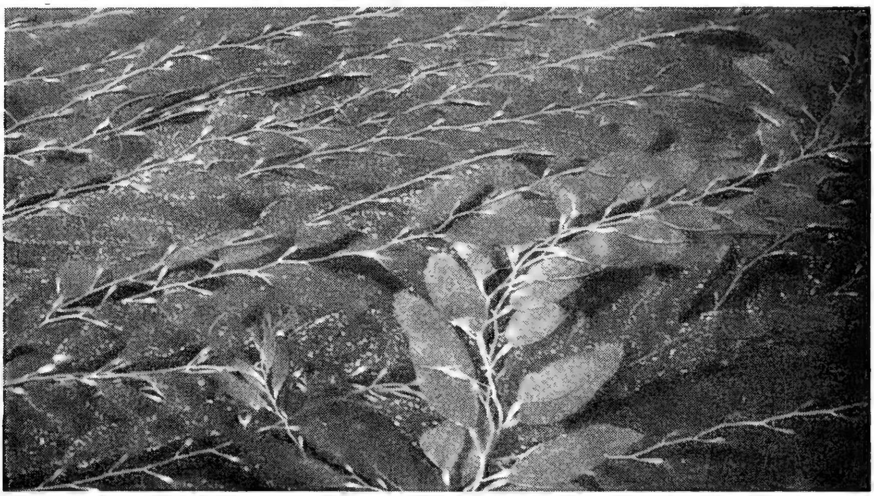
On the European and American coasts of the North Atlantic the "horsetail kelp", *Laminaria digitata,* and the broadleaf or sugar kelp, *Laminaria saccharina,* are harvested for use in making algin. The kelp is usually gathered in motorboats equipped with grappling hooks operating at depths of 10 to 20 feet. Some is also collected in dories by fishermen who rake it from the bottom in shallow water, or gather it as driftweed along the shore after storms.

Along the coast of California and Lower California there are many enormous beds of the giant kelp, *Macrocystis pyrifera,* which are often several square miles in area. Thousands of tons are collected each year south of Point Conception, California. The kelp is harvested by means of an underwater mowing machine carried by a motor-driven barge. A horizontal cutter bar 10 feet or more in length is operated at the bow of the boat about 3 feet below the surface. After the kelp is cut, it is automatically hoisted aboard the barge by an inclined chain conveyor. The edges of the elevator are fitted with knives to prevent it from becoming clogged. Some of the barges hold as much as 300 tons of kelp.

* Hoagland, D. R., "Organic Constituents of Pacific Coast Kelps," *J. Agr. Res.,* 4, 39–58 (1915).

Harvesting kelp in this manner has caused the kelp beds to become more abundant as controlled kelp-cutting stimulates growth and reduces destruction by disease and storms. If kelp is permitted to mature it eventually sloughs off and washes up on beaches in large quantities. Also, older kelp is less resistant to bacteria and parasites.

Several mechanical methods for the harvesting of *Laminaria* are being studied at the Institute for Seaweed Research at Musselburgh, Scotland; some have already been developed. A specially designed grapnel, which is lowered to the bottom, then raised and emptied, has proved satisfactory. A conveyor arrangement with hooks at each link permits a constant flow of seaweed to the boat. Further development of this apparatus is in progress. Another method involves a large, flexible tube with a rotating cutter at one end. The cutting end is dragged along the bottom and the cut seaweed drawn up through the tube with a stream of water by means of a pump. A trawl with cutting blades, or wires, and a rigid wire and metal collecting frame is also being tested.



(Courtesy U. S. Fish and Wildlife Service)

Fig. 6–1. Fronds of the giant kelp (*Macrocystis pyrifera*) float on the surface of the water supported by the gas nodules at the base of each leaf. This plant is one of the several algin sources.

Processes of Manufacturing Algin and Alginates

Stanford's Process. The process used by Stanford in his factory in Scotland during the latter part of the 19th century may be briefly described as follows: Driftweed (consisting chiefly of *Laminaria digitata* and *Laminaria stenophylla*) was macerated (heated or unheated) for 24 hours with one-tenth of its weight of sodium carbonate. The plants completely disintegrated, resulting in an extremely viscous, semigelatinous mass which was difficult to filter. It was necessary to gently heat a cold solution to enable it to filter through coarse filter bags; cellulose, sand, etc. were retained. Addition of either sulfuric or hydrochloric acid pre-

cipitated the alginic acid from the solution in light gray albuminous flocks. It was next filtered in a filter press and washed, forming a compact cake resembling new cheese. It was either sold in this condition or dissolved in a sodium carbonate solution. The solution was then partially neutralized with hydrochloric acid and dried on trays in a well-ventilated room. The sodium alginate was thus obtained in thin, almost colorless sheets, resembling gelatin but very flexible. The filtrate from the alginic acid was evaporated and carbonized and iodine and potassium salts recovered from the char.

The substance which failed to dissolve when the fresh seaweed was treated with the sodium carbonate was left as a residue after the first filtration. Stanford named it algulose or algic cellulose. Although it contained no fiber, it consisted of fine cellular tissue which, according to Stanford, made a transparent and very tough paper. Algulose, dried to a very hard, dense mass, may be used in the manufacture of buttons and knobs, etc.

The Kelco Process. Algin and alginates are manufactured on a large scale by the Kelco Company at San Diego, California and by the Algin Corporation at Rockland, Maine.

Giant kelp (*Macrocystis pyrifera*) is used as raw material by the Kelco Company. This company uses a process, originally patented by Green in 1936, which avoids heating the solutions. It may be briefly described as follows: Freshly harvested kelp is leached for several hours with a weak hydrochloric acid solution to reduce the salt content. The acid liquor is drained and discarded and the kelp chopped and shredded. The product is digested with about 40 to 50 pounds of soda ash per ton to give a pH of about 10. While cold, the resulting gelatinous mass is given a second digestion with soda ash. The product is then completely disintegrated in a hammer mill. Six volumes of water are added and the pulpy mass maintained at a pH of 10.6 to 11.0. This is pumped into a tank where clarifying agents are added and allowed to settle. A diatomaceous earth filter aid is mixed with the supernatant liquor, which is then filtered through a plate and frame filter press.

The filtrate which contains the sodium alginate in solution is then treated with a 10 per cent calcium chloride solution to precipitate the alginic acid as calcium salt. The insoluble calcium alginate rises to the top and the lower layers of the solution containing soluble salts and soluble organic matter are drained and discarded. The curdlike calcium alginate is washed with fresh water and bleached with a dilute sodium hypochlorite solution.

After draining, the calcium alginate is converted to alginic acid by treatment with 5 per cent hydrochloric acid. The excess acid and the calcium chloride are drained off through a screen. The precipitate is rewashed with acidulated water, agitated, and again drained. This process is repeated until practically all of the calcium has been eliminated.

Alginic acid prepared in this way is somewhat unstable and so must be stored under refrigeration. Consequently, it is usually converted to sodium alginate or other alginate by treatment with the proper carbonate, oxide, or hydroxide so that it can be dried for shipment.

Algin Corporation Process. According to this process, which has been patented by Le Gloahec and Herter (1938), either fresh or dried *Laminaria* are soaked in 3 volumes of a cold 1 per cent fresh-water solution of calcium chloride. The sea-

weed is then washed with fresh water to remove soluble materials (laminarin, mannitol, salts) and any remaining calcium chloride until the waste waters contain less than 0.5 per cent soluble matter. Next the seaweed may be washed with a dilute hydrochloric acid solution to dissolve any residual alkaline earth salts. The acid in turn is eliminated by further washing with fresh water.

Then the seaweed is digested with double its volume of a warm 4 per cent soda ash solution. The mass is agitated simultaneously with pulp beaters until the seaweed is comminuted. It may also be vigorously agitated by compressed air pumped through perforated pipes or porous diffuser plates.

The mass is diluted with twice its volume of water by constant vigorous agitation. This produces an emulsion which is pumped into a settling tank. After about 10 hours the cellulose particles flock together and rise to the top, forming a compact, floating cake. The underlying liquid contains crude sodium alginate. This liquor is decolorized by intimate mixture with a jelly composed of colloidal hydrated alumina (or aluminum hydroxide), silica gel, and aluminum alginate. The amount of absorbent jelly used is approximately equivalent to one-fourth of the dry weight of the sodium alginate present. The pigments are selectively adsorbed by the jelly, which is later removed by centrifuging.

The crude sodium alginate solution is then clarified, usually by filtration. The clarified solution is then treated with hydrochloric acid to precipitate the alginic acid. The crude alginic acid is collected and then dewatered in a basket centrifuge. After a final washing with alcohol to purify it further it may be dried at 140° to 160° F (60° C to 71° C) and packed for shipment, or it may be converted into sodium or another alginate by treatment with the proper carbonate, oxide, or hydroxide.

Laminarin, the "phaeophycean starch", may be obtained as a by-product of the manufacture of algin from *Laminaria*. The dilute solution of calcium chloride, which is used to treat the crude *Laminaria*, dissolves laminarin, mannitol and various salts from the seaweed. To recover laminarin from this liquor it is evaporated to a relatively small volume. Alcohol is added to the concentrated solution in an amount sufficient to make up 85 per cent, thus completely precipitating the laminarin. After it has been separated from the solution, the laminarin may be purified by dissolution in dilute calcium chloride solution and reprecipitation with alcohol.

Uses of Alginic Acid and Alginates

Industrial Uses. Alginic acid as such is comparatively limited in its applications. It can easily be molded into any desired shape while wet and retain its form when dry, assuming a hard, hornlike form that is very insoluble and resistant to the action of chemicals.

The properties of the various alginates indicate many uses (Table 21). Sodium alginate is the most versatile of the alginates since it is easily soluble in water and can be readily made into insoluble substances. As a valuable sizing material, it is sometimes used as an adjunct to starch because it fills the cloth better and is tougher and more elastic. Moreover, it is transparent when dry. It imparts a thick, clothy, elastic feeling to goods, without the stiffness of starch. Since its solutions are so viscous, it goes further than starch or any gum. Once the sodium alginate has impregnated the cloth it may easily be made insoluble by treatment

with dilute acids, limewater, salts of calcium, barium, and various other metals. It may be used for the fixing of mordants in fabrics and, to a limited extent, as a mordant. Ammoniated aluminum alginate becomes insoluble after drying and may be used for the preparation of waterproof fabrics.

In Japan, Great Britain, and Russia alginates are actually used in the manufacture of fibers for certain textiles. Textile fibers are produced when a sodium alginate solution is extruded into an acid coagulating bath or one containing a metallic salt solution producing an insoluble alginate. Further treatment or washing will give them added strength.

Alginic acid fibers possess the disadvantage of being soluble in alkaline solutions, but this is not true of chromium alginate and beryllium alginate fibers. Fabrics made from the latter are fire-resistant.

The property of its alkali-solubility finds an application in making certain fabrics in combination with other textiles. If wool and calcium alginate fibers are woven, the alginate can be removed by washing and a gossamer-like woolen fabric will result. These fabrics make lovely evening dresses which are light as the finest cotton fabrics, yet have the warmth of wool.

Another somewhat similar use is in the manufacture of lace. A pattern of some other fiber is woven into a calcium alginate cloth; when the alginate is washed out, a lacy pattern remains. In making astrakhan a loose weft of wool and a tight weft of alginate are woven on a wool warp, and the alginate washed out.

Following the same general principles used in making textile fibers various algin and alginate films and coatings have been prepared. They have an advantage over cellophane since they are almost noninflammable. Algin is utilized to some extent for the coating and sizing of paper to resist the penetration of resins and greases. Alginates are also used in a limited way in the manufacture of wall boards.

The use of alginates for boiler water treatment dates back to Stanford (1884). The virtue of alginates lies in their reaction with calcium in hard water. The precipitated calcium alginate forms globular, flocculent masses which envelop other sediments to yield a soft pasty sludge, most of which can be blown out of the boiler at regular intervals. The alginates also interfere with crystal formation, and thus prevent scale-deposit.

Other industrial uses of algin and alginates include the following: Mucilage and other adhesives, water emulsion paints, ceramic glazes and bodies, porcelain, welding rods, asphalt emulsions, cleaning compounds, detergents, polishes, can-sealing compounds, latex creamers and thickeners, leather finishes, fire-retarding compositions, wire-drawing lubricants, insecticides and oil well-drilling muds.

Pharmaceutical Uses. Alginates also find extensive uses in many pharmaceutical preparations, such as emulsions, tablets, ointments, jellies, and dental impression materials. Other products in which they are sometimes used include: toothpaste, deodorants, shaving cream, mouth washes, shampoo, lotions, beauty "milks", and greaseless hair pomade. Milne (1941) especially recommends its use in vanishing creams and hand "jellies". In making a hand jelly he suggests dissolving 1.5 parts of sodium alginate and 49 parts of glycerol in 35 parts of water, and then adding 0.2 part of calcium citrate rubbed with 13 parts of water. After some perfume has been added, the mixture is allowed to stand for 2 or 3 days.

In the Food Industries. Since algin has been found to be nontoxic and nutritious (Nilson and Lemon, 1942), it has many uses in the food industries. One of the most important uses is as a stabilizer in ice cream, sherbets, ices, chocolate milk, and cheese. During the past few years sodium alginate has come to be more frequently used as an ice cream stabilizer, replacing the less stable gelatin. This is indicated by the smaller size of the ice crystals in the alginate-stabilized products. Sodium alginate also more efficiently retards coarsening during storage and distribution because its enormous hydration capacity is not affected, to any appreciable extent, by temperature changes. Moreover, the whipping ability of mixes containing an algin stabilizer is 35 per cent more than that of similar mixes containing gelatin. The amount of algin used is not limited by the melting characteristics of ice cream since sodium alginate does not form a gel at low concentrations. Aging of ice cream mixes containing sodium alginate is unnecessary because they attain their maximum viscosity almost immediately on cooling and the resulting mixes are quite uniform, regardless of age.

According to Sommer (1938) the advantages of sodium alginate over gelatin as an ice cream stabilizer are as follows: (1) less required, (2) uniform viscosity of the mix during aging, (3) similar or better whipping quality of the mix, (4) lighter color (although the mix is slightly more colored), (5) smoother and cleaner melt-down, without any serum drainage or wheying-off, and (6) "cleaner" flavor. The disadvantage of sodium alginate is its failure to dissolve when added to cold mix. On this account the mix should be warmed to 150° to 160° F (65° to 71° C) before the alginate is added.

Although sodium alginate is valuable as a stabilizer in sherbets and ices, a special alginate composition is required. It is also extensively used as a suspending agent for the cocoa fibers in chocolate milk (Green, Clark, Mann, and Preble, 1937). Only 0.2 per cent of this composition is needed to prepare a smooth chocolate milk of uniform viscosity.

Sodium alginate is also used in making soft cheeses and cheese spreads. Mack (1938) suggested the use of 0.1 to 0.2 per cent sodium alginate in making cream cheese, whole milk cheese of the Neufchâtel type, and cheese spreads. The alginate should be dissolved in hot water and added to the cream before pasteurization. As much as 0.8 per cent sodium alginate may be used in cheese spreads packed in glass containers by the "hot pack process."

Alginates are often employed in many bakery products, such as icings, fillings, meringues, marshmallow toppings, jellies, glazes, syrup, and bread. They are also contained in puddings and similar desserts, confectioneries, French and other salad dressings, flavor emulsions, meat sauces, and whipping cream.

Miscellaneous Uses of Seaweeds

The most important modern uses of seaweed and marine plants, other than those which have been considered, are for fertilizer, animal feed, sizing, paper manufacturing, upholstering, and mattress making. Of these various uses fertilizer is the most general since some seaweed is used in this way on practically every seacoast.

Seaweed as Manure. For many centuries seaweeds have been used to increase crop yields in Japan, China, Great Britain, France, Canada, and many other countries that have extensive seacoasts. When the beneficial results of adding

the water-soluble potassium compounds to growing crops were discovered, they explained, in large measure, the advantages derived from the use of seaweeds and seaweed ashes; for these substances usually contain relatively high percentages of potash.

The use of seaweed as manure is the most general and in some countries the most important. In Great Britain, since the potash and iodine industries have been abandoned, the use of seaweed as fertilizer has become about the most important seaweed industry. No statistics relative to the amount of seaweed used as manure are available since it is rarely sold or transported for long distances. The algae are usually collected in the vicinity of the seacoast by farmers who apply them to their land. Some seaweed is gathered in the New England states; but, except for the giant kelps on the California coast, its use for fertilizer in the United States has always been of only minor importance. Evidently this is because the United States possesses a great abundance of other more easily accessible fertilizing materials.

In addition to the relatively high potassium content (varying from 3 to 17 per cent) the dry matter of seaweeds contains from 1.0 per cent to 7.0 per cent nitrogen. In most common seaweeds the amount of nitrogen in the dry matter varies between 2 and 3 per cent. Much smaller amounts of phosphorus, calculated as phosphoric acid (P_2O_5), are present; the maximum amount is about 1.0 per cent and the minimum about 0.2 per cent of the dry weight. The total amount of fertilizing constituents present in fresh seaweed is comparable to the amount present in barnyard manure. However, seaweed contains a much greater proportion of potassium salts, a much smaller proportion of phosphoric acid, and about the same proportion of nitrogen.

For certain root crops, such as beets and potatoes, the use of seaweed as fertilizer is particularly desirable because they need larger proportions of potash than most other crops. Since seaweed is especially low in phosphorus and relatively low in nitrogenous constituents, materials high in these substances should be mixed with it to obtain a complete and balanced fertilizer.

Nearly all of the potash in seaweed is water-soluble and, therefore, immediately available for plant use. The nitrogen and phosphoric acid which it contains become available only when the seaweed decays. This takes place relatively slowly in the soil. Thus, it is not especially valuable as a top-dressing as it has little water-solubility or readily available nitrogen. If it is mixed with barnyard manure before application, it decays more rapidly when it is applied and the nitrogen and phosphorus become available more quickly.

Algae Used for Stock Feed. In Norway, Scotland, and Ireland herds pasturing along the seashore graze on the fuci exposed at low tide. In Norway and Scotland Irish moss and various rockweeds are gathered, boiled, mixed with meal, and fed to horses, pigs, and cattle. Cattle and horses are not usually fond of seaweed unless they are accustomed to eating it. Furthermore, seaweed is considered poor animal feed since it is not readily digested.

Recently, however, there have been attempts to manufacture chicken and stock feed from rockweed. A "seaweed meal," which is prepared by drying and grinding rockweed (*Fucus vesiculosus*), has been put on the market at Harsted, Norway. This feed, which was said to contain too much inorganic matter, had the following proximate analysis:

Water	6.5%	Protein (N × 6.25)	7.0%
Ash	19.1	Crude fiber	6.2
Ether extract	2.8	N-free extract	58.5

In Denmark it has been proposed that the seaweed be partially digested in manufacture. The fucus is thoroughly washed to remove as much of the soluble salts as possible, cooked with superheated steam, drained, and then pressed into cakes, which are dried in a vacuum and ground into coarse powder. The juice formed during the cooking process is evaporated until a portion of the salts crystallize out. The crystals are separated from the mother liquor in a centrifugal separator and the mother liquor is mixed with the powdered cake. The analysis of the feed is as follows: water, 5 per cent; protein (N × 6.25), 13.12 per cent; crude fiber, 9.0 per cent; and ash, 5.03 per cent.

Because of its mineral and riboflavin content, dried kelp is of considerable value as a component of animal and poultry feeds. In California the giant kelp (chiefly, *Macrocystis pyrifera*) is dried and ground for use in both cattle and poultry feeds. It is a valuable mineral and vitamin (chiefly, riboflavin) supplement to ordinary commercial feeds.

Marine Plants Used for the Making of Mattresses and Upholstery. Eelgrass, or seagrass (*Zostera marina*), which derives its name from its grasslike appearance, finds extensive use in the stuffing of mattresses and furniture. This plant, unlike all the seaweed considered in previous chapters, does not belong to the group known as marine algae, but to the *Naidaceae*, or pondweed family. Unlike algae, it bears submarine flowers, fruits, and seeds. It thrives only on the muddy bottoms of shallow, protected waters and grows principally in brackish water. Important eelgrass industries exist in Great Britain, France, and Holland. The exports of this material from Holland amount to 2,000 to 3,000 tons annually.

The grass is mowed with scythes at low tide. It is necessary for the mowers to work in the water as the grass does not grow above the low water mark. The cut grass is spread in fields to dry. When it is partially dried and has become black, it is soaked for several days in ditches filled with fresh water. It is again spread on the fields and, when completely dry, is taken to the warehouses where it is pressed into bales of about 100 pounds each. The blacker the cured grass, the higher the price obtained for it. Eelgrass prepared in this way is used as a substitute for hair in filling mattresses and upholstering furniture.

Odd Uses for Seaweeds. Many processes of manufacturing paper from eelgrass (*Zostera marina*) have been suggested. Although it contains a relatively small amount of fiber, it produces high quality paper. The manufacture of paper from eelgrass is similar to that from esparto; however, *Zostera* contains less foreign matter and is, therefore, more easily bleached. At various times processes of manufacturing paper from the true marine algae have been proposed, but none of them have been adopted commercially.

Many species of algae are used by the Japanese for decorative purposes. Among them are *Sargassum enerve* (called "moku" or "mo" by the Japanese), other species of *Sargassum*, *Ecklonia bicyclis*, *E. cava*, and various species of *Laminaria*. *Sargassum enerve* becomes an attractive green color when dried and is intertwined with *Laminaria radicosa* to decorate Japanese homes on New Year's Day.

In some parts of the world certain species of seaweed are extensively used in

the manufacture of ornaments and curios. *Laminaria,* having a hollow stipe, are used for knife handles as these seaweeds, when dry, are very hard, wrinkled, and hornlike, yet attractive. The giant kelp, *Macrocystis pyrifera,* has been used in the preparation of a hard substance resembling ebonite, or vulcanized fiber. In making this material the salts are washed out and the kelp is highly compressed and dried.

A submarine plant known as *Posidonia australia,* found on the southern coast of South Australia, particularly in the Spencer and St. Vincent gulfs, contains a valuable fiber which is adaptable for the manufacture of cloth, rope, twine, mats, paper, and stuffing. *Posidonia australia,* like *Zostera,* is not a marine alga as it has greenish flowers and fleshy fruit about the size of an olive. The commercially important part of the plant is the fibrous remains of the leaf sheaths that cover the base of the stem. These fibers are longer and finer than those of *Posidonia oceanica,* the only other known species of the genus, which is found in the Mediterranean and along the European Coast of the Atlantic. The quantity of the fiber in the deposits on the South Australian coast is very large; in Moonta Bay they cover many square miles and reach to a depth of 9 feet or more. The chief difficulty in preparing the fiber is the separation of a large proportion of the waste matter dug up with it.

Various investigators have prepared the sugar, mannitol, from certain species of *Laminaria* and have proposed using these seaweeds as the source of the manna of commerce. *Laminaria saccharina* contains 12 to 15 per cent of this sugar and, when used to make algin, mannitol is obtained as a by-product. In Kamchatka the natives prepare an alcoholic drink from dulse (*Rhodymenia palmata*). Other unusual products that have been made from marine algae are duplicator rolls and rubber compounds.

REFERENCES

Anderson, E. O., Dowd, L. R., and Helmbolt, H., "Sodium Alginate as a Stabilizer for Ice Cream," *Ice Cream Rev.*, **20**, 88–91 (1937).

Andrews, H. L., "The Kelp Beds of the Monterey Region," *Ecology,* **26,** 24–37 (1945).

Anon., "Seaweed Rayon and the Structure of Alginic Acid," *Monthly Sci. News,* **49** (1945).

Anon., "Algin at Work," New York, Booklet published by Kelco Company, 1948.

Anon., "Alginates for the Food Industry," *Food Manufacture,* **24,** 357 (1949).

Atsuki, K., and Tomada, Y., "Studies on Seaweeds of Japan I. The Chemical Constituents of *Laminaria,*" *J. Soc. Chem. Ind. Japan,* **29,** 509–517 (1926).

Bannister, H. W., "Alginates for Water Softening," *Chem. and Ind.,* **1944,** 247.

Barry, V. C., "Preparation, Properties, and Mode of Preparation of Laminarin," *Sci. Proc. Roy. Dublin Soc.,* **21,** 615–622 (1938).

Barry, V. C., and Dillon, T., "Preparation of Alginic Acid and Its Constitution," *Sci. Proc. Roy. Dublin Soc.,* **21,** 285–287 (1936).

Bergy, G. A., "Sodium Alginate in Pharmacy," *Am. Prof. Pharmacist,* **5,** 430–431, 494–495 (1939).

Briggs, S. E., "Sodium Alginate Products in Ice Cream and Chocolate Milk," *State Coll. Wash. Inst. Dairying Proc.,* 85–90 (1936).

Cate, P. H., "Results Obtained with Sodium Alginate in Cold Water or Emulsion Paints," *Am. Paint J.,* **22,** 58, 60, 62 (1938).

Chapman, V. J., "The Kelp Trade," *Nature,* **155,** 673–674 (1945).

Chase, F. M., "Useful Algae," *Ann. Rept. Smithsonian Institution,* 401–452 (1941).

Clow, A., and Clow, N. L., "The Natural and Economic History of Kelp," *Ann. Sci.*, **5**, 297–316 (1947).

Dahlberg, A. C., "A New Method of Manufacturing Cream Cheese of the Neufchâtel Type," *J. Dairy Sci.*, **10**, 106–116 (1927).

Delf, E. M., "The Nature and Uses of Seaweeds," *J. Roy. Soc. Arts*, **91**, 505–514 (1943).

Dillon, T., "Utilization of Seaweed. Its Present and Future Industrial Development," *Chem. Age (London)*, **49**, 279–283.

Dillon, T., and McGuiness, A., "On Alginic Acid: Its Mode of Occurrence and Its Constitution," *Soc. Proc. Roy. Dublin Soc.*, **20**, 129–133 (1931).

Frydlender, J. H., "Sodium Alginate and Its Use in Cosmetics," *Arch. droguerie pharm.*, **7**, 87–88 (1939).

Goodman, C., "Technical Control of Ice Cream with Sodium Alginate," *Ice Cream Rev.*, **18**, No. 7, 42–48 (1935).

Green, H. C., "Process for Making Alginic Acid and Product," U. S. Pat. 2,036,934 (1936).

Green, H. C., Clark, D. E., Mann, R. P., and Preble, B., "Stabilizing Chocolate Milk and Other Milk Products and Process of Making Same," U. S. Pat. 2,097,225 (1937).

Haddan, R., "Making Bread and Other Bakery Products," Brit. Pat. 525,766 (1940).

Hauser, E. A., and Dewey, B., Jr., "Creaming of Rubber Latex," *Ind. Eng. Chem.*, **33**, 127–130 (1941).

Hoagland, D. R., "Organic Constituents of Pacific Coast Kelps," *J. Agr. Res.*, **4**, 39–58 (1915).

Hoagland, D. R., and Lieb, L. L., "The Complex Carbohydrates and Forms of Sulfur in Marine Algae of the Pacific Coast," *J. Biol. Chem.*, **23**, 287–297 (1915).

Le Gloahec, V. C. E., and Herter, J. R., "Method of Treating Seaweed," U. S. Pat. 2,128,-551 (1938).

Mack, M. J., "Sodium Alginate as a Stabilizer for Ice Cream," *Ice Cream Rev.*, **21**, 60–64 (1936).

Mack, M. J., "Sodium Alginate as a Stabilizer," *Food Industries*, **10**, 195–196, 225 (1938).

Mackenzie, W., "Preliminary Investigations of the Possibilities of Harvesting Underwater Seaweed," *Scottish Seaweed Res. Assoc. Tech. Rept.*, E/1 (1947).

Mantell, C. L., "The Water Soluble Gums," New York, Reinhold Publishing Corp., 1947.

Mathews, D. R., "Notes on the Use of Sodium Alginate," *Pharm. J.*, **148**, 79 (1942).

Milne, G. R., "New Types of Toilet Preparations," *Chem. and Drug*, **134**, 145–146 (1941).

Moreland, C. F., "Natural Paper Formed by Dried Algae," *Am. J. Bot.*, **24**, 592–593 (1937).

Nelson, W. L., and Cretcher, L. H., "The Alginic Acid from *Macrocystis Pyrifera*," J. *Am. Chem. Soc.*, **51**, 1914–1922 (1929).

Nieman, C., and Link, K. P., "Synthesis of the Hexuronic Acids II. The Synthesis of *d*-Mannuronic Acid from *d*-Mannosaccharic Acid," *J. Biol. Chem.*, **100**, 407–413 (1933).

Nilson, H. W., and Lemon, J. M., "Metabolism Studies with Algin and Gelatin," U. S. Fish and Wildlife Service, *Res. Rept.*, 4, 1–9 (1942).

Percival, E. G. V., and Ross, A. G., "The Cellulose of Marine Algae," *Nature*, **162**, 895 (1948).

Scheffer, V. B., "The Commercial Importance of Seaweed Gums in the United States," *Fishery Market News*, **5**, No. 6, 1–5 (1943).

Schoeffel, E., and Link, K. P., "Isolation of α and β,*d*-Mannuronic Acid," *J. Biol. Chem.*, **100**, 397–405 (1933).

Sommer, H. H., "The Theory and Practice of Ice Cream Making," 3rd ed., Madison, Wisc., Published by the Author, 1938.

Stanford, E. C. C., "On Algin: A New Substance Obtained from Some of the Commoner Species of Marine Algae," *Chem. News*, **47**, 254–257, 267–269 (1883).

Stanford, E. C. C., "On Algin," *J. Soc. Chem. Ind.*, **3**, 297–301 (1884).

Stanford, E. C. C., "On Alginic Acid and Its Compounds," *J. Soc. Chem. Ind.*, **5**, 218–221 (1886).

Takahasi, T., "Application of Alginic Acid in Textile Processes," *Rayon World (Japan)* **6**, No. 2, 17–23 (1938).

Takahasi, T., "Waterproofing Artificial Fibers from Alginic Acid," Jap. Pat. 133,063 (1939).

Takahasi, T., "Fibers and Films of Alginic Acid," *Rayon World (Japan)*, **7**, No. 11, 11–18 (1939).

Tracey, P. H., "The Use of Stabilizing Agents in Manufacturing Ice Cream," *Ice Cream Trade J.*, **32**, 31–32 (1936).

Tseng, C. K., "Utilization of Seaweeds," *Sci. Monthly*, **59**, 37–46 (1944).

Tseng, C. K., "Colloids from Kelp Give Rise to Unique Process Industry," *Chem. Met. Eng.*, **52**, 97–100 (1945).

Tseng, C. K., "Phycocolloids: Useful Seaweed Polysaccharides," *In* Alexander, J., "Colloid Chemistry: Theoretical and Applied," **6**, 629–734, New York, Reinhold Publishing Corp., 1946.

Tseng, C. K., "Seaweed Resources of North America and Their Utilization," *Econ. Bot.*, **1**, 69–97 (1947).

Tsimehc, A., "A New Rayon—Alginic Acid and Professor Speakman's Beryllium Alginate Rayon," *Silk J. and Rayon World*, **17**, No. 198, 13–14 (1940).

Walker, F. T., "Sublittoral Seaweed Survey (Parts I–III)," *J. Ecol.*, **35**, 166–185 (1948).

Wohnus, J. F., "The Kelp Resources of Southern California," *Calif. Fish and Game*, **28** (4), 199–205 (1942).

Wood, E. J. F., "How Seaweed can Help to Feed, Clothe and House Us," Australian Commonwealth Fisheries Office, *Fisheries Newsletter*, **8**, No. 2, 16–17 (1949).

CHAPTER 7

Pearls and the Pearl Industry

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The Nature of Genuine Pearls

Natural or genuine pearls, composed mostly of calcium carbonate and held together by a tenuous network of organic matter known as conchiolin, are formed when some foreign substance is accidentally ingested into the shell of a pearl-bearing mollusk. The irritant may be a grain of sand, a particle of silt, or a parasitic form of life, such as a trematode. If there is no evidence of an irritant, scientists believe the causative agent to be of wholly organic and internal origin. Shortly after the deposition of pearl substance decomposition of the organic matter ensues, the final product revealing nothing of what initiated the process.

The pearl oyster unable to rid itself of the unwelcome intruder seeks to reduce the attendant irritation by coating the substance with a nacreous material. Once the formation of calcium carbonate has started, the microscopic pearl itself becomes the irritant. The process continues until the organism dies, the pearl is self-ejected, or the mollusk is brought to the surface by man.

A natural pearl, examined under a microscope, structurally resembles an onion in that numerous layers of extreme thinness are concentrically deposited from the innermost to the outermost part of the jewel. The iridescence of a fine pearl can be attributed to the incident light that is reflected and refracted from the surface of its translucent layers.

Pearls have four general shapes: spherical, button and ovoid, pear, and baroque, or badly misshapen. The origin of all the types may well result from any one of the several causes mentioned. These pearls may be formed in different parts of a pearl-oyster's musculature system. Occasionally, the pearl may form as part of the shell; such a pearl is referred to as a "blister pearl."

The finest salt-water pearls are called "oriental pearls" in the trade. The term "oriental," however, should properly be confined to pearls found in the Persian Gulf or those obtained from the waters of Ceylon, and should not include all pearls found in salt water.

Salt-water pearls are formed in shells that have the generic name of *Margaritifera.* There are several species in the genera, ranging from a small shell the size of a man's hand, as those obtained from the Persian Gulf (*M. vulgaris*), to one measuring up to 15 inches across (*M. maxima*), found in the coastal waters off northern Australia.

Natural pearls occur in a wide variety of colors: rose, cream, white gray, bronze, black, shades of lavender, blue, yellow, orange, brown, and green. Black

pearls are rare and valuable, but not more so than the fine rose-colored specimens. Pearls generally assume a color similar to that possessed by the lining of the shell. Changes in the temperature of the water, the state of health and age of the organism, and the kind of food ingested are a few of the factors which could be instrumental in bringing about a variation in color during pearl formation.

The Pearl Fisheries

Persian Gulf Fishery. The richest oriental pearl fisheries in the world are those of the Persian Gulf. Prior to World War I as many as 600 native teakwood boats, or sailing dhows, each carrying an average of 50 pearl divers and helpers, left the port of Bahrein for the pearl fishing waters off the middle Arabian Coast. In the summer of 1947 only 150 boats were engaged in pearl fishing. No diving paraphernalia of any kind is permitted by British authorities, who have jurisdiction over the area, and the natives use the same pearl fishing methods today as their ancestors did 2,000 years ago. Only 35 per cent of the genuine pearls of the Persian Gulf come from the waters around Bahrein. Kuwait to the north and the Trucial Oman Coast to the south supply the remainder.

The routine of pearl diving is as follows: Large oars, extending from the side of the dhow, help to steady and propel the craft and furnish a place to which the descending rope can be attached. To this rope is fastened a stone, weighing about 50 pounds, on which the diver stands. When he is ready to submerge, he takes a deep breath, clamps a clothespin-like device on his nose, pulls the slip knot which frees the rope, and descends rapidly. He carries with him a small net basket which is also fastened to a rope. As soon as he reaches bottom, he plucks as many pearl oysters as possible. While some divers descend to depths of 60 feet, the usual distance is nearer 30. Total elapsed time under water may be as much as 2 minutes; a minute and a half, however, may be taken as average. These men of the Persian Gulf are not physically powerful as are the pearl divers of the South Seas; on the contrary, they are thin and wiry. Age does not appear to be a factor, for men of 70 will be found diving with boys in their teens.

Ceylon Fishery. The intermittent and uncertain pearl fisheries of Ceylon have ranked second in importance to those of the Persian Gulf. They are carried on in the Gulf of Manaar, a 65 to 150 mile-wide arm of the Indian Ocean, separating the island of Ceylon from the southernmost part of India. The pearl-oyster beds, known locally as "paars", are situated off the northwest coast of Ceylon and also in the neighborhood of Tuticorin, on the Madras Coast of the mainland. These fisheries are almost as ancient as those of the Persian Gulf; they are alluded to in Singhalese records as early as 550 B.C., and Pliny wrote of them.

As a rule the fishery begins in late February or early March. The important fishery from 1902 to 1907 was centered at the improvised settlement of Marichchikadde. But few Singhalese participate in comparison with the large numbers who assemble from India, Arabia, and elsewhere. A short time after it has been officially announced that a pearl fishery will take place at Marichchikadde on the Island of Ceylon, a populous town springs up. The fishing fleet consists of several hundred boats of various rigs and sizes, the number of persons on each boat ranges from 12 to 65. The season is short, only some 6 or 8 weeks at the most. The divers work in pairs, each pair sharing a single diving-stone and descending alternately.

The Red Sea Fishery. The Red Sea fisheries date back to ancient times, having been exploited centuries before the Christian era. Later they were surpassed, but not superseded, by those of the Persian Gulf and Ceylon, and they have continued to be a good source of supply up to the present day. The largest and best known pearl oyster here is the variety identified by Jameson as *Margaritifera margaritifera erythroeensis,* which is closely related to the large species in the Persian Gulf. It measures 4 or 5 inches across, although it occasionally attains a diameter of 8 inches and a weight of 3 pounds or more. It is distinguished by a dark green coloring about the edges and by a greenish hue over the interior nacreous surface. Although it only rarely yields pearls, the shells afford good qualities of mother-of-pearl and the occasional pearls add to the profit of the catch.

The pearling season usually lasts from March or April until the end of May and is renewed in September and October. Dhows, holding from 40 to 80 men or sambuks (sailboats without decks), holding from only 6 to 25 men, are used.

Venezuelan Fishery. On the coast of Venezuela the *Margaritifera radiata* is the chief pearl oyster, a species related to that of Ceylon, although slightly larger in size and having a coloration range from white to bronze, and occasionally black. Pearl fishing in these waters under European direction dates back to 1500 A.D. The islands of Cubagua, Coche, etc., lying near the larger island of Margarita, constitute a group. While the average size of the pearls from this field was rather small, so great a quantity was attained toward the close of the sixteenth century that the fifth part of their value, the tribute paid to the King of Spain, amounted to more than 15,000 ducats annually. Then the product rapidly decreased. After 1845 pearl fishing revived and by 1909 as many as 350 boats, all small craft of from 2 to 15 tons each, were engaged in the enterprise.

Panama Fishery. The richness of the Panama pearl fisheries on the Pacific Coast was made known to the Spaniards in 1526 by Gonzalo de Oviedo, and many of the finest pearls in the Spanish treasury were derived therefrom. However, like the Venezuelan source, the production gradually declined, and recently its success depends almost entirely on the value of the pearl shells. The principal reefs and headquarters of the fishery are at Archipelago de las Perlas, or Pearl Islands, situated from 30 to 60 miles southeast of the Pacific terminus of the Panama Canal. The pearls are of good quality, frequently of large size; they range in color from white to green and lead-gray and are often greenish black. The Panama mollusk is much larger than that of Venezuela and hence furnishes a fine shell.

Mexican Fishery. The pearl fisheries on the Pacific Coast of Mexico were reported to the Spaniards in 1522 after conquest by Hernando Cortés. From a tribe near the present site of Hermosillo, in the State of Sonora, Cortés secured great quantities of the gems, and the location of the pearl reefs was prominently noted on his coastal map, made in 1532. In the eighteenth century one of the most successful of the early pearlers, Manuel Osio, is credited with having marketed 127 pounds in 1743 and 275 pounds in 1744; he is said to have been the richest man in Lower California. In 1868 the yield of pearls was about $55,000. The fishery was then carried on from shore camps or from large vessels, each carrying 20 to 50 divers, most of them Yaqui Indians. The season lasted from May until late September. The principal species of pearl-mollusk in this region is the

Margaritifera margaritifera mazatlanica, which is closely related to the "black-lip" shell of the Australian coast. It is considerably larger than the Venezuelan oyster, averaging from 4 to 5 inches in diameter and sometimes attaining 7 or even 8 inches. Another species, *Margaritifera vinesi,* occurs only in the northern part of the Gulf, near the mouth of the Colorado River.

The Australian Fishery. Although many fine pearls have been found in the Australian fisheries, they are principally exploited for pearl shells and are, therefore, described in the section on mother-of-pearl. The value of the pearl yield in the northwest Australian fisheries for 1906 was estimated at £50,000, that of the Queensland fishery, £33,000, and that of South Australia, £5,000, a total of £88,000, or nearly $430,000. Relatively few seed pearls are secured. Some beautiful examples of large pearls have been found, but they usually possess less lustre than the Persian or Indian product and their form is less regular.

One of the finest Australian pearls was that taken by one of the luggers of Messrs. James Clark and Company's fleet near Broome, Northwestern Australia, late in 1917. It weighed 100 grains, was 18 mm long, 15 mm in diameter, and had a circumference of 45 mm. The bottom end was flat for a width of 7 mm. This pearl was valued at £20,000.

Malaysian Fishery. The best known of the Malaysian pearl fisheries are those of the Sulu Archipelago, Philippine Islands. The pearls obtained were available to the rest of the world as long as 400 years ago, and in 1520 Pigopitta, a companion of Magellan, reported them to be among the prized possessions of the natives. The pearl-oyster reefs extend from Sibutu Pass to Basilan Strait and roughly cover an area of 15,000 square miles. The large mother-of-pearl oyster, *Margaritifera maxima,* is by far the most abundant, but the Australian "black-lip," *Margaritifera margaritifera,* is also found.

Other Fisheries. Among the pearls which are contained in certain other mollusks are pink pearls. They are sometimes found in the *Strombus gigas,* the giant conch shell of the West Indies. Unfortunately, they are not nacreous and do not preserve their hue very well. *Strombus gigas* is one of the largest of the univalve shells, some measuring as much as 12 inches in length and weighing 5 or 6 pounds. An exceptionally fine example of a conch pearl has been sold in New York for $5,000, the gem having been brought from Nassau in the Bahamas. Pearls are occasionally found in the *Turbinella scolymus* and in the Indian chank (*Turbinella rapa*), which produces pink and red varieties. The *Pinna squamosa* furnishes some brown pearls of poor quality. On the other hand black pearls from the pearl oyster of the Gulf of Mexico command high prices.

Fresh-water mussel pearls are found in many of the lakes and streams in certain sections of the United States. In the past Iowa and Arkansas were the leading suppliers of fresh-water pearls. These pearls, while often beautiful (fine ones are exceedingly rare), do not command the prices obtained from genuine salt-water pearls of equal size and beauty. It is very difficult to obtain in any quantity fresh-water pearls of approximately the same color, and they are usually more misshapen than the pearls grown in salt water.

It should be mentioned here that fine pearls are never found in edible oysters. What is sometimes found is nothing more than a gray, worthless calcareous mass or concretion. These so-called "pearls" are in no way related to the pearl found in the shells of *Unio* or *Margaritifera.*

Characteristics of Genuine Pearls from Various Sources

Panama pearls are predominantly silver-gray in color and superficially resemble some Australian types. Australian pearls are characteristically silver-white or lead-gray in color. Pearls of 100-grain weight and larger are not unusual because the shells in which they are found often measure 14 inches across. Pearls from the Persian Gulf, Red Sea, and Ceylon waters are pinkish in color. These regions supply the world with the finest pearls. The southeast coast of the Celebes and Molucca Islands are famous for their black pearls. Tahiti and New Guinea are other sources of fine black or greenish-black pearls. Pearls from the Gulf of California are frequently of the black or greenish-black variety. In years past this region was noted for pearls of this color. Venezuelan pearls have a characteristically yellow cast.

Some genuine pearls are occasionally found in the same waters in which are grown Japanese cultured pearls. The genuine, as well as the cultured, have a greenish-yellow color when extracted from the pearl oyster. In most instances the Japanese dye their cultured pearls pink or rose to make them look like the genuine pearls obtained from the Persian Gulf. All Japanese blue, black, or bronze cultured pearls have been dyed.

Evaluation of Pearls

Form. According to form and appearance pearls have been designated as follows. "Paragons": large or exceptionally beautiful; "round": perfectly spherical; "button": domed on top with a flat or slightly convex back; "pear-shaped"; "drop-shaped": elongated, but larger at the lower end than the true "pear-shaped" pearl; "egg-shaped"; "cone-shaped": elongated, but with one flat end; "top-shaped": flattened at the top, but with rounded sides; "seed-pearls": round or irregular, weighing a quarter grain or even less; "dust-pearls": so small as to be almost valueless; "petal pearls": rather flat, one end often being more pointed than the other; "hinge pearls": found near the hinge of the shell and further differentiated as "wing pearls" and "dog pearls", the former slightly resembling a wing, the latter pointed, elongated, and narrower; "slugs": irregular and distorted, often consisting of an aggregation of imperfect pearls; "hammer pearls": shaped like a hammer; "baroque": having no typical form; and "half-pearls": usually made by cutting off the best rounded section of an irregularly formed pearl.

Value. As a general rule the worth of pearls may be estimated by establishing a base value for a gem weighing 1 pearl grain (50 mg) and then multiplying this amount by the square of the number of grains that any given pearl weighs. For example, if the base value is determined to be \$1, then that would be the worth of a 1-grain pearl; but a 2-grain pearl would be worth 4 times as much ($2 \times 2 = 4$), or \$4, while a 10-grain pearl would be worth \$100 ($10 \times 10 = 100$). The origin of this system of valuation can be traced back to the sixteenth century, when Van Linschoten learned of it in India. The base value of a pearl necklace can be determined in the following way: If the center pearl weighs 25 grains, multiply 25×25, the result being 625; then take the next 2, 3, or 4 pearls, as many as are of approximately the same weight, add their weights together, multiply the resulting figure by itself and divide the product by the number of pearls in the group. Carry out this system with the remaining pearls, grouping them according

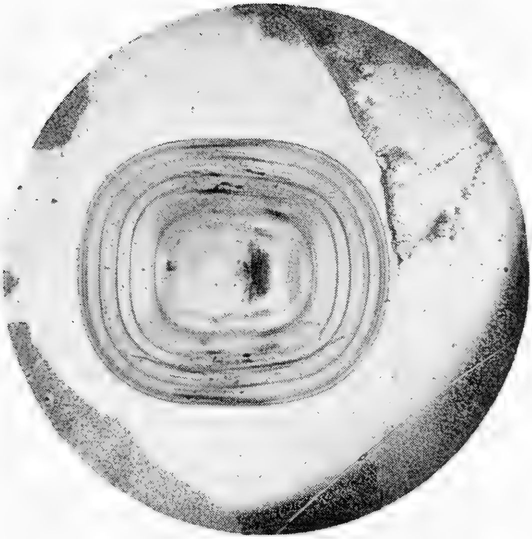


Fig. 7–1. Thin section of natural fresh water pearl. Note annual growth rings.

(Photo by A. E. Alexander)

Fig. 7–2. Thin section of natural salt water pearl.

(Photo by A. E. Alexander)

to their weights, add all the quotients together, and divide the price of the entire necklace by this number to ascertain the multiple or base value.

While it was entirely possible for a person to spend $60,000 for a single flawless pearl of very fine orient in 1929, the same pearl would sell for only a very small fraction of this amount today. The drop in price can be attributed in part to the introduction of Japanese cultured pearls following World War I.

Utilization in Jewelry

Drilling. Pearls require no polishing or cutting prior to setting as in the case of precious stones. The most important operation in preparing them for use as ornaments is drilling. Formerly this was a laborious process, and even a skillful driller could not perforate more than 40 or 50 ordinary pearls in a day by means of a bow-drill operated by hand. However, with one of the modern machines 1,500 pearls of average size can be pierced in the same time. The bow- or fiddle-drill is preferred for piercing fine pearls. The arm of this is made either of steel or wood, with a strong cord stretched across it in the style of an archer's bow. This drill is inserted in the end of a circular brass disk, with a V-shaped groove on its edge to allow the string to be passed entirely around it like a pulley. When the drill is in place and held at the other side and the bow moved up and down, the wheel with the drill rotates rapidly. Of late years drill-holes have been much reduced in diameter in order to preserve as much as possible the weight of the gem.

When the pearl is not absolutely perfect, which is seldom the case, the poorest part is chosen to form the beginning of the drill-hole. Large pearls are put in a pair of calipers, one arm of which is placed on the spot to be pierced, the other of course touching the opposite side. The end of each caliper arm is rubbed with a little rouge or lampblack which leaves a mark on the pearl. The drill is then placed on the mark and the bow moved up and down. The work is so rapidly performed that 5 large pearls, weighing 15 grains, can be drilled in less than an hour's time; with small pearls the operation is performed much more quickly.

Stringing. In stringing pearls for a necklace the thread, which is invariably of the finest quality silk or nylon, is passed through the metal eye of the object serving as a clasp; a knot is then made and the thread passed through the end pearl. Another knot is made, and so on, until all the pearls have been strung and the thread has been firmly secured in the opposite section of the clasp. Should there be a sufficient number of pearls for the designated length of the necklace, knots are only made at every third, fourth, or even fifth pearl. The silk thread must neither be dyed nor contain any chemicals. One end is usually stiffened by pure gum arabic dissolved in water. To avoid any danger of the thread being cut, the holes in the pearls are carefully reamed out until they become quite smooth. In the case of a long chain or sautoir as many as 300 pearls may be strung on a single row, and great skill is needed to accomplish the task properly. Necklaces require restringing according to the frequency with which they are worn. If, when the thread is stretched, it can be seen between the pearls, or at either end, this is an indication that they must be restrung.

In the case of a collar, 13 or 14 inches long, there are frequently 23 rows of pearls, kept straight by 4 jeweled bars. When there are from 10 to 25 pearls in

a section between the bars, the entire collar may consist of 2,000 small pearls.

Mounting. Many of the pearls mounted as studs or in rings are set upon a peg. This is done to reveal the full size of the pearl; for if it were held in place by claws, part of it would be hidden. The use of a double peg prevents the pearl from turning and thus becoming loosened and falling off the peg. The jeweler must exercise great care in mounting a pearl so that the settings will not scratch or otherwise mar it.

Cultured Pearls

The most ingenious development in pearl artifice involved the channeling of these natural processes into mass production methods. The original conception of this industry is attributed to the Chinese. As early as the thirteenth century the Chinese discovered that, by placing an object such as a small image of Buddha in a living fresh-water mussel and returning the organism to its natural environment, a deposit of nacre was slowly built up around the nucleus. It was not until 1890 that present day commercialization of the Chinese discovery was begun.

There have been several attempts in recent years to culture fresh-water pearls in the United States. One culturist undertook the work in the San Saba River, Texas. Although several fresh-water cultured pearls were grown, the enterprise failed. Spherical glass beads were used as irritants instead of the usual mother-of-pearl cores.

The founder of the Japanese cultured pearl industry was Kokichi Mikimoto. After much discouragement he succeeded in producing blister or baroque pearls about 1894. Some 15 years elapsed before he successfully produced a wholly spherical pearl. The Japanese process consists (according to Japanese published accounts released by the firm of Mikimoto) of removing from a living oyster the mantle parenchyma which is used as a bag to envelop the nucleus of the pearl. When this nucleus, which consists of a fragment of fresh-water mussel, has been inserted into the bag, its mouth is secured with a cord and the whole is introduced through a surgically made opening into the subcutaneous tissue of the shell-secreting epidermis of another oyster. In the same operation the cord is withdrawn, the wound made by the lancet disinfected, and the oyster, having been returned to the sea, left to cover the nucleus with as many layers of nacre as necessary to produce perfectly spherical pearls.

Since publication of these data there has been considerable advancement in the technique of growing cultured pearls. It was found, for example, that it was unnecessary to make a "surgical" operation on the pearl oyster; instead, one or more mother-of-pearl beads may be inserted into the mantle parenchyma to start the process of calcium carbonate deposition around the nucleus or irritant. In short the whole enterprise is now one of mass production. Of the total number of pearl oysters "set", it is believed that only 60 per cent will produce cultured pearls of salable value. A much lower percentage of this total will yield fine, flawless pearls.

Prior to World War II Japanese pearl culturists carried on their work, not only in the waters surrounding Japan, but around the island of Palau in the South Seas. By using the large Australian type shell cultured pearls up to ¾ of an inch could be grown in that region.

Certain salient facts about Japanese cultured pearls are unknown. Through

clever propaganda, disseminated since World War I, the Japanese have led many prospective buyers to believe that cultured pearls and genuine pearls are one and the same thing. They claimed that only a "tiny irritant" is used to initiate the process. Scientific tests, based on the sectioning, thin-sectioning, and X-raying (radiography) of thousands of pearls of Japanese origin, have shown that these pearls contain mother-of-pearl beads that measure from 75 per cent to 90 per cent of the total diameter. The average thickness of nacre (pearl substance de-

FIG. 7–3. Inserting mother-of-pearl bead in pearl oyster.

(Photo by Robt. O. Smith)

FIG. 7–4. Pearl oysters in cages in which they are held at a depth of about 35 feet until the "cultured" pearls develop.

(Photo by Robt. O. Smith)

posited around the mother-of-pearl bead) is found to be only from one-half to one mm. Thus Japanese cultured pearls have only a veneer of pearl surrounding the core. Furthermore, Japanese sources state that it takes from 7 to 9 years to "grow" a cultured pearl. Actually the pearl oyster is capable of depositing one-half mm of nacre in one growing season, or 1 year. In fact the Japanese culturists

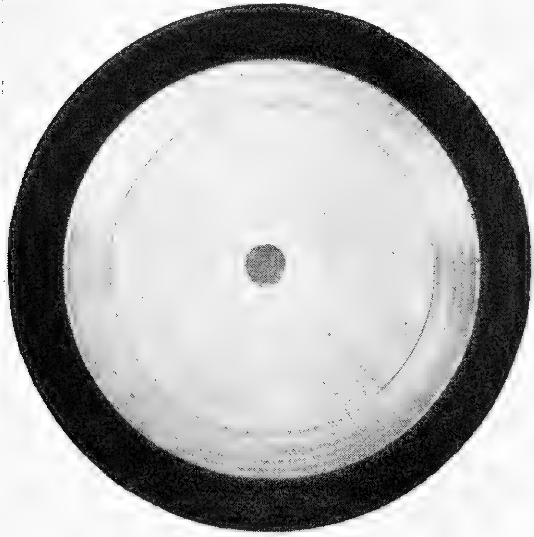


FIG. 7–5. Thin section of a Japanese cultured pearl. Note large mother-of-pearl bead.

(Photo by A. E. Alexander)

often inject various chloride solutions into a pearl oyster to expedite the deposition of calcium carbonate. It thus seems apparent that a cultured pearl takes only a year or two to be produced.

Japanese cultured pearls are usually yellowish green. The pink color of the cultured pearl, such as seen in a department store, is due entirely to the introduction of a pink or red dye. After the pearls are drilled, the dye solution penetrates the porous microscopic layers existing between the outer nacreous coating and the mother-of-pearl core. Since the coating is only one-half to 1 mm thick, and translucent as well, the dye imparts a pink tint. Any black cultured pearls seen on the market also owe their color to dye.

There is no *easy* way to differentiate between a cultured pearl from a natural one. Checking the specific gravity or density is of no avail. Pearls can be fluoroscoped, radiographed, and subjected to X-ray diffraction methods. The latter techniques are relied on almost entirely. On the basis of the information obtained the pearl expert can quickly and positively distinguish between genuine, cultured, and imitation pearls.

Pearl Essence and Imitation Pearls

A Frenchman named Jaquin discovered in 1656 some methods for making imitation pearls. When the silvery material found on the surface of many species of fish was applied to beads, it gave them a luster closely resembling that of pearls. At first solid beads were coated with a gelatin solution containing pearl essence.

But although these imitation pearls were beautiful, the coating was not waterproof. Later the interior of hollow glass beads was coated with the "essence" and then filled with wax. Although these imitation pearls were not damaged by water, they were easily crushed. However, it became possible to make "indestructible" pearls by coating opal glass or other solid beads with a suspension of the pearl essence in a waterproof lacquer. This is the most popular type of imitation pearls produced today.

Most species of fish owe their sheen to a deposit of thin blade-like crystals of guanin in the epidermis of their scales. When the epidermis is rubbed off under water, it is partially disintegrated and lustrous particles are suspended. If this suspension of guanin crystals is strained through cheesecloth to eliminate coarse particles, crude pearl essence settles to the bottom.

Guanin, chemically speaking, is 2-amino-6-oxypurin ($C_5H_5N_5O$), a derivative of purin, and belongs to the group known as the purin bases. In the animal body it occurs with other groups in nucleic acids, which in turn are combined in the complex proteins found in cell nuclei. Guanin is insoluble in water, alcohol, ether, chloroform, ethyl acetate, amyl acetate, acetaldehyde, acetic acid, acetic anhydride, formic acid, lactic acid, or solutions of citric or salicylic acid. It is very slightly soluble in cold ammonium hydroxide and more soluble in hot ammonia solutions. It is soluble in dilute mineral acids and in solutions of potassium and sodium hydroxide.

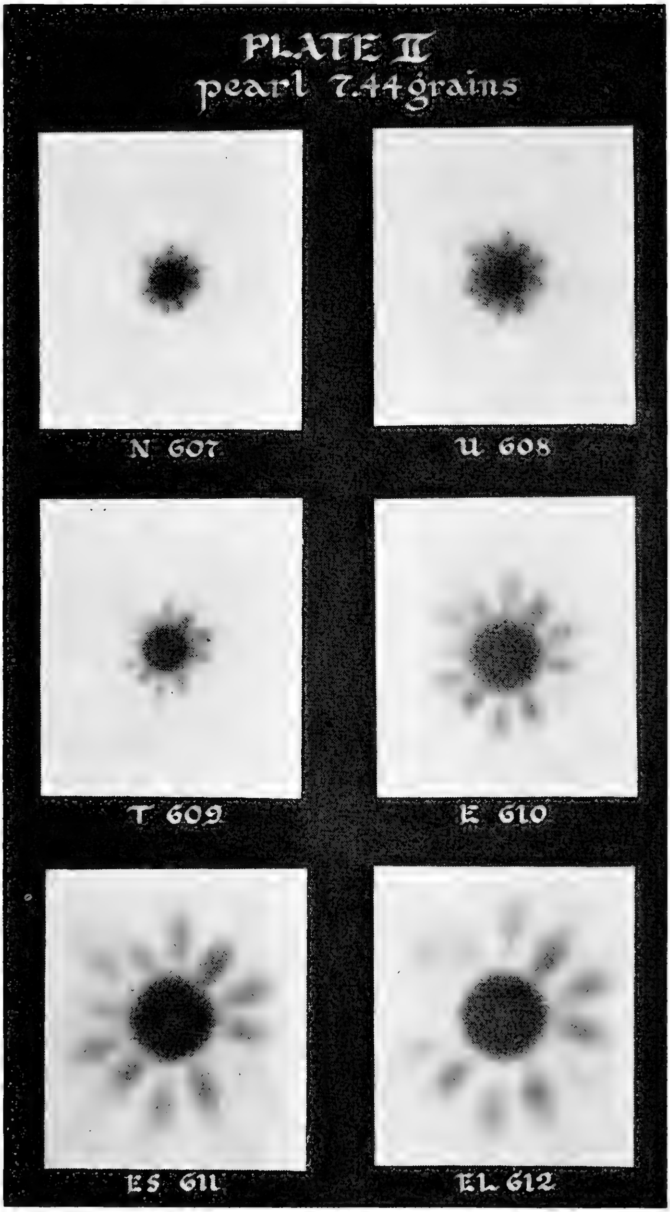
American Source of Pearl Essence. The principal source of pearl essence in America is the herring (*Clupea harengus*) which is caught in great numbers along the North Atlantic Coast from Sandy Hook to Labrador. Several plants for the manufacture of pearl essence from herring are located on both the Canadian and U. S. sides of the Bay of Fundy. Some is also manufactured from the scales of the alewife (*Pomolobus pseudoharengus*) in Massachusetts and Virginia.

Other potential sources are shad, hickory shad, California sardine or pilchard, gizzard shad, mullet, menhaden, Pacific Coast salmons, Alaska herring, and the whitefish and cisco fisheries of the Great Lakes.

Scales accumulate in the bottoms of the boats used to transport the herring from the traps or weirs to the canneries and fish salting plants. To effect an easy separation of the scales from the fish special boats with false bottoms, called "scale scows", have been devised. The false bottoms permit the scales to find their way to the space between the two bottoms, and the fish are held by the upper or false bottom. A hogshead of herring will yield 27 to 34 pounds of scales.

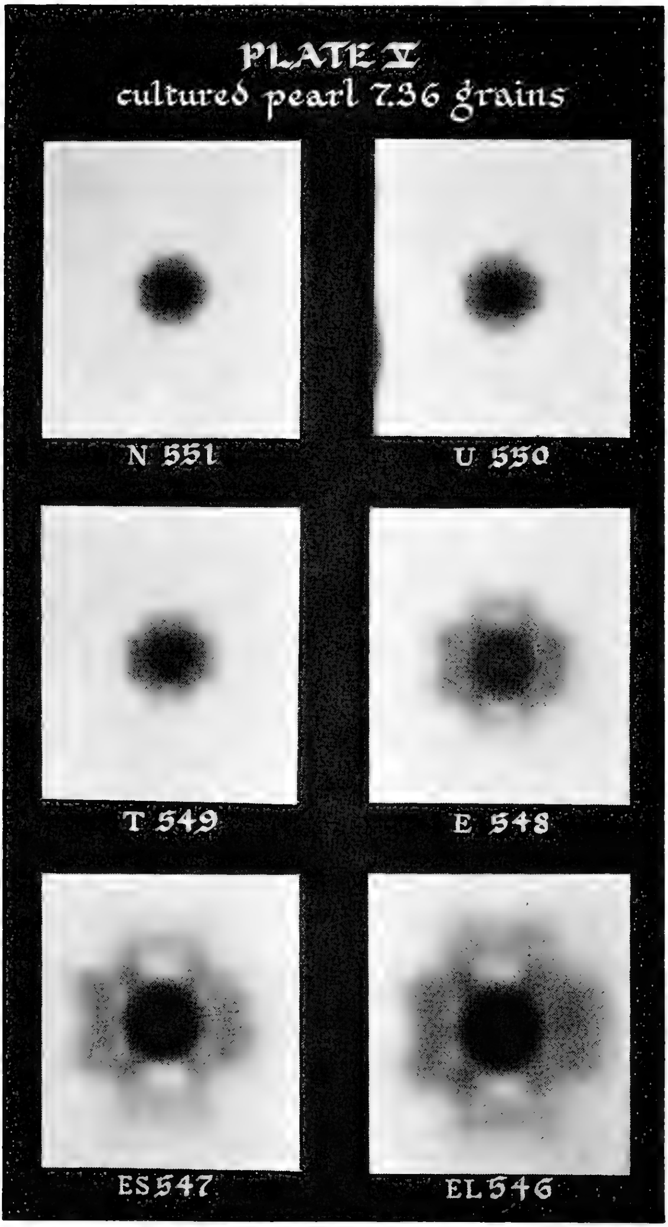
Processes of Making Pearl Essence. First the lustrous material from the scales is scrubbed off in a large agitator, constructed like the old-fashioned ice cream freezer. Only a little water is used. Then the lustrous sediment is separated from the wash water. This is usually done in a basket centrifuge. When the partially dried sediment is scraped out of the basket, it is ready for purification.

Aqueous Suspensions. Aqueous suspensions of the lustrous crystals may be prepared by repeatedly treating the crude product with a dilute ammonia solution. After each treatment the crude essence is allowed to stand in a cool place until the crystals settle; then the ammonia solution is decanted and the treatment repeated several times. The ammonia gradually dissolves the epidermis and leaves the crystals sufficiently clean for use. Pearl essence prepared in this way can be preserved indefinitely if sufficient ammonia is present.



(Photo by Tiffany & Co.)

Fig. 7–6. Natural pearl X-ray diffraction (Laue) pattern. Compare with pattern obtained from a cultured pearl.



(*Photo by Tiffany & Co.*)

FIG. 7–7. Cultured pearl X-ray diffraction (Laue) pattern. Compare with pattern obtained from genuine pearl.

Nonaqueous Suspensions and Lacquers. Pearl essence is often marketed in the form of suspensions in acetone and amyl acetate. It is also sold in the form of lacquers which contain a suspension of guanin crystals in a cellulose ester solution. The methods of preparing these lacquers are either trade secrets or, in some instances, patented processes. Taylor's process of preparing such a lacquer, however, is not patented.* It has been described as follows:

The scales (they need not be clean) are washed free of adhering lustrous matter and the water is drained off. This suspension in water is allowed to subside and the supernatant water (and blood) decanted off. The remaining thick fluid, containing lustrous particles of guanin, is treated with a digestion mixture of pepsin, 2½ gm, and acetic acid (glacial), 30 cc to each liter of fluid, and allowed to stand for 48 hours. This mixture completely digests and removes all proteinaceous matter from the guanin crystals. Hydrochloric or other mineral acids cannot be used to activate the pepsin because these readily dissolve the guanin crystals, while acetic acid does not.

After 48 hours' digestion in the pepsin-acetic acid mixture the surfaces of the guanin crystals are clean. Since they now possess the peculiar property of being more readily wetted by ether and certain other nonaqueous liquids than by water, they are separated from the fluid mass, as follows: Ether is poured into the vessel containing the digestion mixture and guanin crystals and allowed to form a separate layer on top. The vessel is then gently rocked. The lustrous crystals of guanin, being more readily wetted by the ether, leave the water and pass into the ether layer, leaving behind all dirt, organic matter, and the like. Fatty substances also pass into the ether, but the crystals are allowed to settle out. The oily ether is decanted and replaced. The ether (which should now be strictly anhydrous, as by treatment with calcium carbide) is replaced once or twice, removing all the oil or fat. The lustrous material, now clean, can be kept indefinitely in ether, or easily transferred to ethyl or amyl acetate. High grade nitrocellulose (celloidin or "Parlodion") is dissolved in the ethyl or amyl acetate, forming a pearl lacquer which is applied directly to the bead. Ethyl acetate is preferable because it evaporates more quickly. Large quantities of pearl "essence" or lacquer can be readily produced by this process.

The particles of guanin should be neither too coarse nor too fine. The finest particles, consisting of minute fragments of crystals when separated from the coarser ones, appear chalky white or yellowish; if too small they make dull pearls. The larger crystals have a grainy coating and are likely to be too brilliant. Crystals of intermediate size produce the more desirable pearly luster. Large crystals can be broken in a pebble mill containing 5 million glass beads; the grinding is best done in a concentrated suspension of the crystals in amyl acetate.

Manufacture of Imitation Pearls. Imitation pearls are of four major types: (1) Those made by coating the inside of hollow glass spheres with pearl essence. (2) Those made by coating the inside of hollow glass spheres with pearl essence and then filling the spheres with wax or some other material to give weight to the pearl. (3) Those made by coating the exterior of solid glass (known in the trade as alabaster) spheres with pearl essence. (4) Those made from plastic beads; either a naturally lustrous plastic or a plastic with a coating containing mother-of-pearl may be used.

* Taylor, 1925; also the 1923 edition of "Marine Products of Commerce."

The imitation pearl business is very large; in 1948 one company alone made 5 billion plastic cores for imitation pearls. During the decade 1939 to 1949 the amount of pearl essence used in making imitation pearls in the United States increased from about 10,000 pounds to approximately 20,000 pounds.

Hollow Glass Beads. The hollow glass beads used in making imitation pearls are of two types. The cheaper ones are made by blowing thin glass tubing into a mold, resulting in a number of connecting bulbs which are cut apart after the glass cools. These beads are coated inside with a suspension of pearl essence in gelatin solution. When this is dry, the beads are filled with paraffin or other wax. Such beads are light and will usually float on water. Sometimes barium sulfate is added to the wax to make them heavier and whiter.

The better grade of hollow beads is made of specially selected, soft, colorless glass tubing. The tubing is sealed at one end with a blowtorch and a bulb of the desired shape and size is blown. A sheet metal mask, with a hole slightly larger than the hole desired in the bead, is pressed against the end of the bulb or bead, and a small pointed flame is directed against the hole. A hole is blown through the glass and the edges retracted and smoothed by brief contact with the flame. The bead is then cut away from the glass tube. The hole at the cut end is also smoothed in the flame with the help of the mask. After these beads have been coated inside with a pearl essence suspension in gelatin solution or in a lacquer, they are filled with wax or wax containing barium sulfate.

Solid or "Indestructible" Imitation Pearls. Solid beads made of opal glass are often used for the "indestructible" type of imitation pearls. The exact degree of opalescence affects the appearance of the finished bead and is varied in practice to give the desired tint. The beads are made from glass tubing, having a capillary bore of the right size for stringing. The tubing is cut into short lengths and strung on a small iron or copper wire so that these pieces are held in a gas flame and rotated until the desired globular shape is attained. Then they are removed from the flame and rotated until cool.

Another method of making beads, used on a large scale, is to tumble the short lengths of tubing into a mixture of fireclay and graphite until the holes are plugged. They are next placed in an iron drum containing powdered talc which prevents them from sticking together. The drum is slowly revolved while it is heated hot enough to soften the glass and the pieces slowly assume the desired globular shape. They are revolved slowly as they are cooled. After they have been cleaned and the clay-graphite mixture removed from the holes, the beads are ready for coating.

Alabaster Beads. Many of the best imitation pearls are made from alabaster beads (Roberts 1949) which are usually handmade. A drop of molten alabaster on a wire is spun in a flame until a smooth, round bead is obtained. After cooling, the wire is dissolved in acid, leaving a hole in the center of the bead for stringing. The resultant bead is translucent and makes a beautiful imitation pearl.

Dipping the Beads. In making imitation pearls the opal glass, alabaster, or plastic beads are coated with a lacquer containing lustrous guanin crystals in suspension. One commonly used lacquer comprises 50 gm of guanin crystals, 35 gm of 20-30 nitrocellulose, and 369 gm of amyl acetate per pound; 4 to 10 coats of this are applied to the bead. To prepare such a lacquer it is only necessary to dissolve nitrocellulose in a suspension of pearl essence in amyl acetate. If

concentrated lacquer is used, it may be mixed with a clear lacquer containing approximately 10 per cent nitrocellulose.

In effecting the actual dipping operation a "toothpick" is pushed into the center of each bead. As many as 500 toothpicks with a bead affixed to each are put into holes in large dipping boards. One or two boards with beads on the underside are lowered until the beads are submerged in the pearl lacquer. After a moment the boards are raised, removed from the dipping frame, examined, and mounted on a machine which rotates them slowly to insure an even coat while drying. Each dip takes from 1 to 2½ hours to dry. When dry, the coated beads are dipped again. The cheaper imitation pearls are given 4 or 5 dips, whereas the high grade ones receive 8 or 10 dips. The rooms in which the dipping is carried out should be free from dust and preferably air-conditioned.

Threading and Clasping. The final step in the production is threading and clasping. The imitation pearls are graded and matched, then strung on strong thread. Double nylon thread is used for the best necklaces.

Colors. Imitation pearls are made in a wide variety of colors: rose, pink, cream, white, grayish white, orchid, peach, yellow, green, various shades of blue, bronze, gunmetal, and black. These colors are imparted by tinting the lacquers with dyes.

Other Uses for Pearl Essence. Lacquers and plastics containing pearl essence are used to decorate many articles: mirror backs, manicure and toilet sets, jewelry boxes, umbrella handles, opera-glass handles, electric light switches, automobile dashboard fixtures, etc.

REFERENCES

Pearls

Alexander, A. E., "Pearls through Artifice," *Sci. Am.*, **160**, No. 4, 228–229 (1939).

Alexander, A. E., "Science Dissects the Pearl," *Sci. Am.*, **160**, No. 5, 294–297 (1939).

Alexander, A. E., "Pearl Formation Induced by a Rotifer," *Am. J. Sci.*, **237**, 920–922 (1939).

Alexander, A. E., "An X-ray Study of Aragonite in Natural and Cultured Pearls," *Am. J. Sci.*, **238**, 366–371 (1940).

Alexander, A. E., "The Radiography of Cultured and Natural Pearls," *The Gemmologist*, **10**, No. 113, 45–48 (1940).

Alexander, A. E., "The Rate of Seasonal Deposition of Pearl Aragonite," *Science*, **93**, No. 2405, 110–111 (1941).

Alexander, A. E., "Natural and Cultured Pearl Differentiation," *Gems and Gemology*, **3**, No. 1, 2, 169–172, 184–188 (1941).

Alexander, A. E., "The Mineralogy of Five Unusual Natural Pearls," *The Gemmologist*, **10**, No. 119, 93, 96 (1941).

Alexander, A. E., "Fossil Pearls," *Sci. Am.*, **165**, No. 2, 85 (1941).

Alexander, A. E., "All Pearls Are Not What They Seem," *J. Gemmology*, **1**, No. 1, 2–4 (1947).

Alexander, A. E., "Baroque Cultured Pearls," *The Gemmologist*, **17**, No. 201, 95 (1948).

Alexander, A. E., "Spectroscopic Investigation of Pearls," *The Gemmologist*, **17**, No. 203, 134 (1948).

Alexander, A. E., "A Fabulous Genuine Pearl," *The Gemmologist*, **17**, No. 208, 282–283 (1948).

Alexander, A. E., "Care and Treatment of Pearls," *Jewelry Magazine*, **5**, No. 9, 46–47 (1948).

Alexander, A. E., "Pearl Fishing in the Persian Gulf," *Gems and Gemology*, **6**, No. 2, 38–41 (1948).
Alexander, A. E., "Pearls 100,000,000 Years Old," *The Gemmologist*, **18**, No. 210, 1 (1949).
Alexander, A. E., "Pseudo-Cultured Pearls," *The Gemmologist*, **18**, No. 218, 221 (1949).
Anderson, B. W., "The Density of Natural and Cultured Pearls," *The Gemmologist*, **8**, No. 94, 166–169 (1939).
Bolman, J., "The Mystery of the Pearl," Internationales Archiv für Ethnographie, Leiden, 1941.
Haas, F., "The Structure and Formation of Pearls," Akademische Verlagsgesellschaft, M.B.H. (Frankfort A/M), Leipzig, 1932.
Kunz, G. F., and Stevenson, C. H., "The Book of the Pearl," New York, Appleton-Century-Crofts Inc., 1908.
Smith, G. F. H., "Gemstones," New York, Pitman Publishing Co., 1949.
Smith, R. O., "Survey of the Fisheries of the Former Japanese Mandated Islands," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **273** (1947).
Tressler, D. K., "The Wealth of the Sea," New York, Appleton-Century-Crofts Inc., 1927.
Webster, R., "Stained Pearls and X-rays," *J. Gemmology*, **2**, No. 2, 51–54 (1949).

Pearl Essence

Anon., "Pearls by Diptank," *Industrial Finishing and Painting News* (Sherwin Williams Co., Cleveland, O.), **1**, No. 2, 8 (1941).
Anon., "The Silvery Scales of the Herring," *American Fisheries*, **1**, No. 2, 17–18 (1947).
Anon., "Lumarith Cores Make Possible Simulated Pearl Trend," *Celanese Plastics*, **5**, No. 8, 1–2 (1947).
Carter, N. M., "Pearl Essence from Scales of British Columbia Herring," *Fisheries Research Board Canada Prog. Repts.*, Pacific Coast Stations, **55**, 18 (1943).
Roberts, A. G., "Pearls without Oysters," *Gemmologist*, **18**, No. 211, 34–38 (1949).
Taylor, H. F., "Pearl Essence; Its History, Chemistry and Technology," U. S. Bureau of Fisheries Doc. **989** (1925).
Tressler, D. K., "The Wealth of the Sea," New York, Appleton-Century-Crofts Inc., 1927.

CHAPTER 8

Mother-of-Pearl and Blister Pearls

Mother-of-Pearl

Introduction

Mother-of-pearl is widely used for decorative purposes. It is impossible to estimate accurately the world's annual production of pearl objects, but it is probably in the neighborhood of $100,000,000. The marine pearl-shell fisheries are located principally in Australia, the Netherlands Indies, the Philippine Republic, Japan, the Persian Gulf, the French Pacific Islands, India, and New Zealand. Manufacture of pearl buttons is centered in the United States, England, France, and Japan. Italy and France use large quantities of pearl shells for the manufacture of jewelry and ornaments.

Practically the only marine mother-of-pearl shells produced in the United States are those taken in the abalone fishery of southern California and in the scallop fishery of the Atlantic Coast. However, thousands of tons of fresh-water clams, taken from the Mississippi River and its tributaries, are used to make pearl buttons and other useful ornaments.

According to the U. S. Department of Commerce the United States imports of unmanufactured mother-of-pearl shell in 1948 totaled 5,288,718 pounds, valued at $2,513,727. Australia was the leading supplier of these shells, sending 1,422,603 pounds, valued at $1,005,925. The Netherlands Indies supplied 1,181,932 pounds, valued at $570,363; the Philippine Republic, 935,334 pounds, valued at $388,826; the French Pacific Islands, 529,525 pounds, valued at $188,980; and New Zealand, 264,113 pounds, valued at $94,103. Smaller quantities came from some 15 or more additional areas. United States imports of mother-of-pearl manufactures (including shells and mother-of-pearl engraved, cut, ornamented or manufactured) amounted to $13,808, principally from Italy and France.

Great Britain carries on a considerable traffic in shells, which is especially important in the commerce and industry of many of the outlying divisions of the Empire. Australia is the largest contributor to the British shell market.

Structure and Composition

The shell of the pearl oyster is formed of three main layers, the outermost designated as the periostracum. Within this is the "prismatic layer", which is thicker than the outermost layer and constituted by an aggregation of calcareous columns or prisms disposed at right angles to the periostracum. In this, as in other parts of the shell, there is a combination of organic and inorganic substances. The organic part, termed conchiolin, is a nitrogenous substance similar to keratin, forming a kind of network for the deposition of carbonate of lime. Within both of

these layers lies the most important one, the nacreous layer, consisting of mother-of-pearl. This layer is secreted by the external surface of the mantle of the oyster and may continue to increase in thickness during the animal's existence. Its structure is composed of a series of exceedingly thin plates (laminae), overlapping one another and arranged parallel to the shell's surface. Since the mother-of-pearl surface shows both the faces and zigzagged edges of the laminae, it displays, through the phenomenon of light interference, the iridescence designated as nacre.

Pfund (1917) found that the thickness of the laminae for many different samples of mother-of-pearl from a fresh-water mussel (*Obovaria ellipsis*) (Lea) lies between the limits of 0.4μ and 0.6μ.

Clement and Riviere (1922) studied the deposition of calcium carbonate in an albuminous medium and were able to obtain deposition in the form of a diffraction grating of a physical structure, resembling mother-of-pearl, which possesses the same property of iridescence.

Species Utilized

The principal genera of mollusks utilized commercially for the manufacture of mother-of-pearl objects are *Margaritifera* Jameson, or *Meleagrina, Gasteropoda, Trochus,* and *Haliotis.* Certain species of the genera *Pinna, Malleus, Trigonia,* and *Nautilus* are also taken, but these mollusks are of lesser commercial importance.

Margaritifera maxima Jameson, the large white mother-of-pearl shell of Australian, Papuan, and Malayan waters, commercially called "silver-lip", "gold-lip", etc., *M. margaritifera,* the "Bombay", "Tahiti", "Gambier", "Auckland", "Panama" shell, etc., *M. vulgaris* Jameson, the Ceylon pearl oyster, and *Margaritifera radiata,* the Shark Bay shell, are the species of *Margaritifera* or pearl oyster of the greatest commercial importance. *Haliotis splendens, H iris,* and *H. mida* are the species of abalone which are utilized to the greatest extent. The species *Turbo olearius,* or *marmoratus,* and *Trochus dilatatus* (*niloticus*) of the genus *Gasteropoda* are of more commercial value than other species of that genus. The species of Trochus shell fished in Australian waters is *Trochus* (*Rochia*) *niloticus* Linne. It has a larger base whorl than the *Trochus maximus,* which is common in the Philippine waters.

Geographical Distribution

Margaritifera vulgaris **Jameson.** This small species of shell grows only to about the size of a silver dollar, is generally dirty white or yellowish in color, and weighs from 8 to 50 shells to the pound. It is fished principally for pearls.

These shells are used only in the manufacture of cheap shirt buttons. When market conditions are bad or freight high, it is not profitable to ship them. In this case they are dumped in enormous piles on the beach and allowed to deteriorate. Often, however, after years of exposure, they are reclaimed. As many as several tons of these shells, buried for years in Shark Bay, have been thus dug out and shipped to Europe. They are not used industrially in America.

Lingah *—*Persian Gulf.* Great quantities of pearls are obtained near Bahrein.

Western Australia—Shark Bay. The fishing here has been carried on for about 80 years. Although formerly very productive, it has been "over-fished." It is now

* In the trade all the *Margaritifera vulgaris* are called "Lingahs."

slowly recovering and produces perhaps 200 tons per year. There is no fishing south of Shark Bay.

Venezuela (Porlamar). Here very inferior small shells are fished almost exclusively for pearls. The shells are often full of veins and very thin. They are rarely used industrially. These oysters are probably of a different species.

Belbil. In the southern part of the Red Sea *Margaritifera vulgaris* are found alongside the regular shell in such small quantities that they are hardly worth freight charges.

Margaritifera

White Shells (Various Species). *Sydney.* Large white shells, weighing up to 1 pound each, are found in this region. They are also termed "Queensland" or "Thursday Island" shells. There is a great fishery here.

Port Darwin. This is a small fishery in the northern part of Australia, from which the finest white shell has been secured.

Western Australia. The shells found here are also called "Fremantle" by the English trade as it was formerly the most important port of shipment for white shells. Not as large nor as fully developed as the "Sydneys" or "Aroes", they weigh up to about 1 pound each.

Aroes. These shells are also called "Macassars", from the former shipping port; now most of them are shipped directly from Dobo. There are two kinds of shells of similar quality. Those called "native-fished" have been recovered by hand. The deep-water fishing with scaphanders produces many old and defective shells.

The mother-of-pearl furnished by the Netherlands East Indies has been regarded as some of the best in the world. The chief fisheries are those of the Aroe Islands near the southwest coast of New Guinea. As is commonly the case with native industries, the methods employed are very primitive. The work is done principally from February to April. As the Chinese compete actively in the purchase of mother-of-pearl, good prices are obtained.

The United States is by far the most important market for higher quality white shells. Some go to England for knife handles, etc., and only the very poorest are taken to Central Europe, where they are made into small buttons.

Yellow Shells. Yellow shells, curiously enough, are located only in an area which is close to that inhabited by the yellow races. They are found from Lower Burma, along the Malay Peninsula and Sumatra, and also in the numerous islands of the Dutch East Indian Archipelago, the area ending abruptly in the southern part of the Philippine Islands.

These shells often grow to enormous size, sometimes weighing as much as from 2 to 3 pounds apiece. The center is often perfectly white, while the lips and the part close to the bark are often dark yellow or almost brown. By cutting a cylinder out of any of these shells the top layers can be utilized for white work and the lower parts for inferior purposes.

Singapore. This comprises a mixture of all sorts of yellow shells from the various islands where they are fished, such as Bangay, Bima, Batjan, Solor, etc., and formerly derived to a great extent from shipments from the Philippines, where the Chinese merchants of Singapore have their Chinese correspondents. The various qualities are made into uniform mixed lots.

Manila–Zamboanga, or Sulu. Called "Manila Shells," they are fished in Mindanao (Zamboanga) and the Sulu Archipelago.

New Guinea, or Moresby Shell (Port Moresby). This is an inferior yellow shell, often almost copper-colored, and the fishery is unimportant.

Mergui–from Mergui, Lower Burma. The best of the yellow shells, they are very thick and white.

Green Shells. While the expressions "white," "yellow," or "black" are commonly used in the trade to describe the shells, "green" shell is not in general use. It seems to denote inferior grade, dirty, greenish-white color, and much smaller size.

Red Sea. These shells are called "Egyptians" because they were formerly shipped to Europe via Egypt (Cairo). This trade ceased long ago, and now they go directly from their original port via Suez. The Red Sea shell is brought into the ports of Jeddah, Suakim, Massawa, and Aden.

While fishing is carried on in many parts of the Red Sea, the great fishing grounds are the two island groups, Dahlak and Farsan. Massawa in Eritrea is now the principal export center. Most of the "Egyptian" shells go to Austria and Bohemia, where there is an old-established industry.

Zanzibar. These shells are inferior to "Egyptians" as they are smaller in size and copper-colored.

Mussels. This is a highly inferior kind of greenish shell fished in quantities alongside the Lingahs in the Persian Gulf. They are thin and have enormous black lips, resembling the razor-shell. In Austria they have been, and perhaps still are, used for cheap buttons, the local name being "Ohrnaschel" or "Earlobe."

Panamas. These shells are, generally speaking, smaller than the "Egyptians" and of inferior grade. They have a dirty-white line and are often very thick. Aside from the Venezuelan Lingahs they are the only known American shells. According to origin these are the Panama shells proper, fished within a short distance of the town of Panama.

Costa Rica. This is a shell of rather better quality, more yellow than green, but very often worm-eaten and riddled with holes.

Lapar–Acapulco–Mazatlán. These comprise the three grades of shells from Lower California and Mexico. They are similar to "Panamas" in size and general aspect, but are dark-edged.

Black Shells. These shells are used for fancy buttons. However, the industry suffers from the employment of buttons made of inferior grades of shell, but dyed so as to look genuine. Their chief origin is the Pomota group of islands, where the French Government has each year opened a fishery. The shells are generally called "Tahitis," but represent many different qualities. "Hikueru" is generally considered the best; other origins are the Raiatea and Fukarara.

Gambier. These islands produce an inferior black shell.

Fiji. A poor class of black shell is obtained here.

Green Snails (*Turbo marmoratus*). These snails are used for buckles, buttons, inlaid work, etc. They are taken in Penang, Singapore, Mergui, Australia, and New Guinea. Those from Penang and Singapore are considered the best, those from Australia and New Guinea the worst since they are harder and have a peculiar thick ring around the bottom which cannot be utilized industrially.

Trochus. France has been the only country to exploit *Trochus* in steadily increasing quantities up to thousands of tons. At the outset most of it came from

Singapore, but was later fished all over the world. Today the Red Sea fisheries (Jibuti, Massawa) and those of Australia are of great importance. The Fiji Islands, New Caledonia, and Australia are producing various qualities of *Trochus* for industrial purposes. So far only small quantities have been brought to the United States as they are difficult to handle and to process. For many years enormous quantities of *Trochus* buttons have been imported into the United States from France and Japan.

Haliotis (Abalones). These shells exhibit a splendid range of colors and are consequently used for inlaid work (opera-glass cases, etc.) and also for buttons. In Japan they are known as "Awabi," or "ear shells," but constitute an unimportant article of commerce.

Green Ears—Red Ears—Blue Backs. These are not very important commercially. They originate in California and the lower peninsula. The "red ears" are almost worthless; the "blue backs" make a cheap button; and the "green ears" are adapted for fancy work and inlays as the color is vivid. An inferior kind of "green ear" comes from New Zealand.

Mother-of-Pearl Fisheries

Fishery Methods. The pearl, mother-of-pearl, and blister pearl fisheries are in reality one fishery; for the shells of mollusks yielding pearls are nearly always utilized for their mother-of-pearl. On the other hand in many fisheries, as in the Australian, mother-of-pearl is the chief product and pearls a valuable by-product.

The methods employed in taking pearl shells are, of course, the same as those of the pearl fisheries (naked diving, scaphander diving, and dredging). Since these have been described in the preceding chapter and in the chapter on Sponges (page 747), and since it is obviously impracticable to discuss the details of these methods as employed in the various shellfisheries, these points will not be considered in this section.

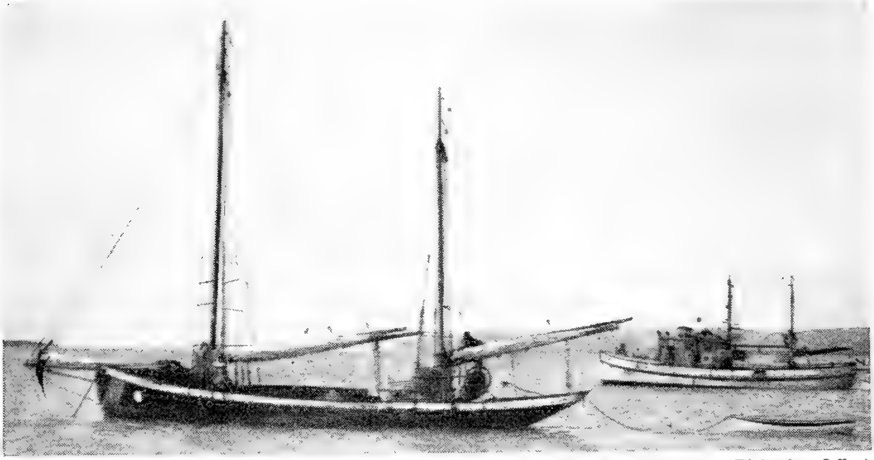
Australian Fisheries. The Australian pearl fisheries are the most important in the world for the production of mother-of-pearl. They have been in active operation since 1868, especially on the northwestern coast of Australia from Cape York to the Northwest Cape, a distance of 2,000 miles. To these fisheries must be added those of the Torres Straits and Queensland. The chief revenue is derived from the pearl shells although a certain number of pearls found become the property of the captain of the fishing craft.

The pearl-shell grounds of Queensland, Australia extend northward from Thursday Island almost to the shores of New Guinea, as well as westward from Booby Island, eastward from Bramble Bay, and southward to Cooktown. For many years the center of the fishery has been Thursday Island. The pearl shell found there is the *Margaritifera maxima* Jameson. The less valuable smaller variety, locally termed "black-lip," *Margaritifera margaritifera,* is taken principally in relatively shallow water.

According to the Australian Commonwealth Fisheries Office the average yearly production in Australia for the period 1932 to 1941, inclusive, was 2159 tons of pearl shell, with approximately 180 fully equipped boats operating. In the 1947 season 91 boats were used. Of these, 70 were the usual 52-foot ketch type; the rest included a torpedo recovery craft, an M.F.V. type, and 8 regular size and 13

small cutters. In that year the total production of pearl shell (*Trochus* shells not included) was 803 tons, worth about $2500 per ton.

In the Queensland fisheries all shells are inspected by a government official before exportation and no shell measuring less than 5 inches across the nacreous surface is permitted to be exported. The pearl fishery is conducted solely for the raising of mother-of-pearl shell, not for the beautiful gems the shells sometimes



(Courtesy Commonwealth Fisheries Office)

Fig. 8–1. Type of pearling vessel at Thursday Island.

contain. It is remarkable that, in spite of the large quantity of shells recovered, fewer pearls occur in the Queensland shells than in those from other fisheries.

In the early days of the Australian fishery shell was picked from the bottom of shallow waters by naked divers, but as the industry expanded, competition forced the exploitation of new off-shore beds, thus necessitating the introduction of the diving dress, mechanical air pump, larger vessels, and more costly apparatus. Although Europeans successfully undertook the work of deep-diving, they were gradually displaced by Asiatic divers.

Since the end of World War I diving equipment has been materially improved with a consequent lessening of risks. The introduction of the British Admiralty's methods of "staging"—allowing the diver to remain for periods at certain depths on his final ascent of the day so that his body may become adjusted to pressure differences—has proved a satisfactory preventive for the dreaded diver's paralysis, or "bends," which has claimed hundreds of victims during the brief history of the fishery. Another innovation for lessening the fatigue of divers has been the practice of towing the diver just off sea bottom until a patch of shell is located. The diving suit and the methods used in diving are much the same as those used in fishing for sponges.

Society Island Fisheries. A considerable quantity of mother-of-pearl shell is exported from Tahiti, Society Islands to the United States. The beds give no indication of approaching exhaustion, and the fishing is carefully safeguarded by the colonial government. As a rule the native divers and shellfishermen have to

be refitted each season. The low price of pearl shell tends to retard extensive exploitation.

Philippine Pearl Shell Fisheries. While exact data regarding the output of the Philippine pearl shell banks are not available, it has been estimated that the annual yield of "gold-lip" pearl shells is probably between 300 and 400 tons,

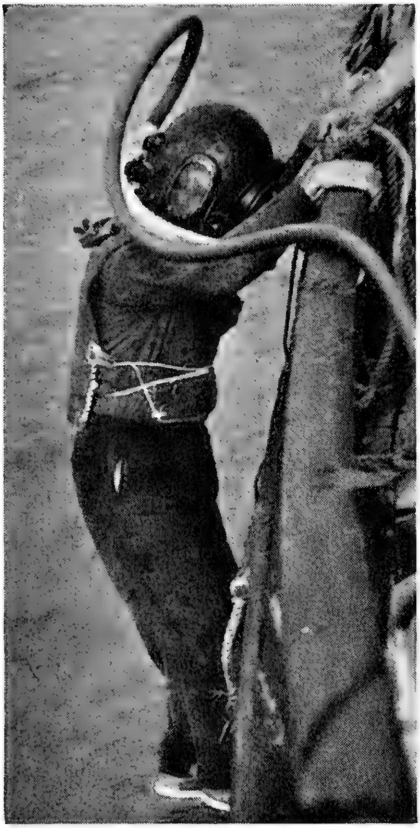


FIG. 8–2. Diver about to descend at Thursday Island. Thursday Island divers use helmet and corselet only instead of full diving equipment.

(Courtesy Commonwealth Fisheries Office)

valued at from $175,000 to $200,000. A certain number of these shells are exported unprocessed and the remainder made into buttons and other objects. The value of the annual pearl yield is placed as high as $500,000, the proportion of pearls being larger than those of the Australian or Celebes fisheries.

Trochus Shell Fisheries. New Caledonia and the neighboring New Hebrides supply France with considerable quantities of *Trochus* shells. The Macassar fisheries, comprising the whole of the Dutch East Indian possessions, are a source of supply for France and Japan.

A considerable quantity now comes from Australia, most of it being taken from the Torres Straits and the Barrier Reef. In 1947 the approximate total in tons was 499, Thursday Island yielding 392, Cairns 92, and Derby 15. Approximately the same amount was taken from 1932 to 1941. These shells are about 3 to 4 inches high and almost smooth. Beneath the outer surface, which is frequently

encrusted with marine growth, lies solid mother-of-pearl. *Trochus maximus* is as suitable as pearl shells for the manufacture of the smaller type of pearl buttons. Since the species live in shallower water, they can be collected with comparative ease.

Cutters and luggers are used for procuring *Trochus* shells from Australian waters. These boats settle near the reefs while dinghies are sent out to find the shells. The divers then go overboard and collect as many as possible. Diving is

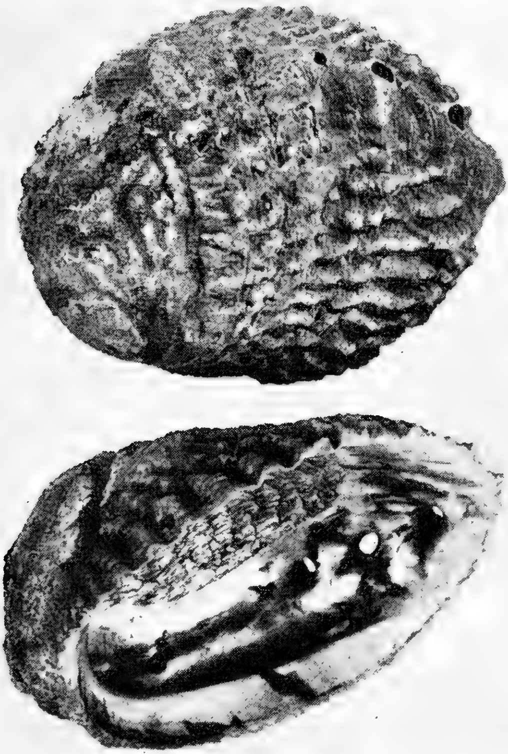


FIG. 8–3. Abalone shell (upper) the outside of the shell, (lower) inside the shell. These shells are valued because of their beautiful coloring and are made into many kinds of ornaments.

(Courtesy U. S. Fish and Wildlife Service)

usually carried out in about 2 fathoms of water, but may extend to 6. Upon the dinghies' return the shells are placed in a copper boiler to cook. From 10 tons of shellfish a ton of *Trochus* meat is obtained. After boiling, the entire "snail" is shaken out of the shell; if not eaten by the crew, it is dried and smoked for a few days, and then exported. Smoked *Trochus* meat is soaked in water until soft, cut into dice, and used as a base for soups and other foods.

The California Abalone Fisheries. The most important abalone fisheries in California are located at the Santa Catalina and San Clemente Islands. These abalones (*Haliotidae*) are sought by pearl fishermen because of the beauty and brilliancy of their nacreous covering. As the zoological name indicates, they resemble the human ear.

A crew of 1 diver and 6 assistants explore the fishing grounds until the abalones are located. The diver then descends and pries them loose by means of a chisel.

After about 6 minutes the net, filled with some 50 green and corrugated abalones, is hoisted aboard. During his shift on the bottom the diver gathers from 30 to 40 basketfuls, each containing about 100 pounds of abalones, or, altogether, 1½ to 2 tons. A few naked divers work in water up to 20 feet in depth, but it requires 6 men to take as many abalones as 1 man in a scaphander.

The meat of the abalones is considered a delicacy by connoisseurs of seafoods. Abalone "steaks" command a high price.

Black, red, and green shells are obtained. In polishing these shells they are first ground on an abrasive wheel until the desired colors are reached. The surface is polished further by a felt wheel sprinkled with silicon carbide dust. Finally it is polished with a wheel made of many layers of cotton on the edges of which tripoli has been rubbed. A single shell yields as many as 15 pieces of mother-of-pearl suitable for ornaments. Scimitar-shaped paper knives are often cut from the shells.

Japanese Mother-of-Pearl Fisheries. Although the pearl fisheries of Japan are not extensive, except in a few localities, the aggregate yield has been considerable. The "awabi," or "ear-shell" (*Haliotis gigantea*), found on the coast of Japan, Korea, etc., furnishes many pearl forms, although this species is much smaller than the California abalones. Its smooth, nacreous surface is unfortunately lessened in value by the size of the marginal perforations. Its opalescent tints adapt it well for the manufacture of certain types of buttons and buckles; but it is chiefly used for inlays, its fine texture and beautiful coloring recommending it highly for this purpose.

The Indian Chank Fisheries. About 2,500,000 chank shells are taken annually in India where that mollusk (*Turbinella pyrum*, Linn.) is considered sacred by the Hindus. The chief fisheries are located at Tinnevelly, Ramnad, Travancore, Kathiawar, Ceylon, and along the Carnatic coast. The shells are taken principally by native divers, although in shallow water some are taken with hooks. This fishery is ancient, dating back more than two thousand years. The chank shells are manufactured into bangles and other ornaments for Indian trade.

Classification of Shells

Size and Quality. The various kinds of pearl oyster shells have been thus classified in the English market:

1. Bold (large)
2. Medium
3. Large medium
4. Small medium
5. Chicken (bark)
6. Dead (dead bark)
7. Pieces
8. Broken
9. Pickings

Certain special designations refer to the source, as for example:

"Ceylon" indicates shells of the *Margaritifera vulgaris* Jameson, fished in the Gulf of Manaar near Ceylon. These shells are brilliant and do not exceed 3½ inches in length; they are thin, and the valves are prolonged into posterior wings at the hinge. The nacreous stratum is very thin.

"Mergui" refers to shells of the *Margaritifera*, fished in the Burmese Archipelago of Mergui. Here are also secured shells of the *Turbo marmoratus* which are green and therefore called green snail mergui.

"Sulu" (Jolo) are shells fished in the Archipelago of Sulu; since they are yellowish on the edges, they are denominated white yellow-edged shells. They measure from 7 to 10 inches and have a thick and lustrous stratum of nacre, which is white with yellowish reflections.

Color. Pearl shells may be divided approximately as follows:

White Shells: West Australia, Port Darwin, Macassar.

Yellow Shells: Manila (Sulu), Mergui, Bina, Singapore. This class comprises yellow shells secured in a great many small islands of the Dutch East Indies and brought to Singapore by Chinese traders.

Green Shells: Among these may be counted Egyptians, Bombays, Panamas, La Paz, Costa Ricas; they have a more or less inferior degree of whiteness, often with a greenish tinge, the outer rim or edge being generally of a darkish hue.

Black Shells: These come from the South Sea Islands, the Paumoto Group (Tahiti), the Gambier Islands, and in lesser quantities from many islands of the South Pacific, such as Fiji, Banda, etc.

Grade. White shells from Western Australia and the Azores and Sydneys are graded in Australia as follows: AA, 36 pounds per 100 shells; A, 36 to 60 pounds per 100 shells; B, heavy medium, 65 to 90 pounds per 100 shells; C, bold, 100 to 130 pounds per 100 shells; D, good defective; E, rough defective. Yellow shells from Manila and Ceram are thus sorted in London: Bold, anything over 75 pounds per 100 shells; medium and chicken, anything up to 70 pounds per 100 shells. La Paz and Panama shells are sold in bulk or sorted into sound and defective. Shark Bay and Lingah shells are not graded. Black shells from Tahiti, Auckland, Bombay, and Egypt are graded thus: A, bold, 70 pounds and upward per 100 shells; B, light bold, 40 to 50 pounds per 100 shells; C, 30 to 40 pounds per 100 shells; D, 18 to 27 pounds per 100 shells.

Manufacture of Buttons

It is generally believed that the first production of buttons from pearl shells on a commercial basis took place in Austria about two centuries ago; Red Sea shells, brought by way of Constantinople, were used. The industry has grown in size and importance and is one of the principal users of mother-of-pearl. It is centered in the United States, Austria, Hungary, France, Germany, England, Italy, Spain, and Japan.

According to the 1948 Census of Manufactures the United States produced 6,810,135 gross of fresh-water pearl shell buttons, valued at $5,396,511, and 4,974,073 gross of marine mother-of-pearl buttons, valued at $8,587,011. The industry is carried on chiefly in New York City and its environs; there are a few scattered factories in Connecticut, Pennsylvania, Maryland, and Iowa.

France is one of the leading European producers of mother-of-pearl buttons although formerly large quantities were exported from Austria, Hungary, and Germany. Great Britain also utilizes much mother-of-pearl for button manufacture. A great button industry has been developed in Japan; prior to World War II Japan was a strong competitor of France.

In the manufacture of pearl buttons those of first quality are made from the part of the shell nearest the hinge and used in the finest shirt and cuff buttons. The thinner parts of the nacreous coating are used for buttons of cheaper quality.

As a first step a disk is cut out of a somewhat larger diameter than that required for the button, then reduced to the size of the button by means of a triangular steel file of fine temper and with a very obtuse point. Due to the considerable and variable hardness of the mother-of-pearl only an expert workman can perform the task satisfactorily; he must always be on the alert to feel the degree of re-

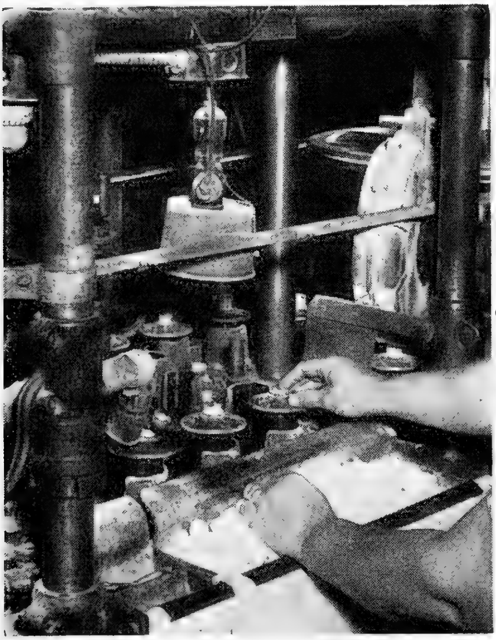


FIG. 8–4. Facing and drilling pearl buttons with Barry machine.

(Courtesy American Pearl Button Co.)

sistance and regulate the pressure of the tool. An expert operator can make from 12 to 22 gross of buttons in a day. The perforation is generally done by women, one of whom can pierce in a day 30 gross of buttons having 4 perforations. After these operations of forming and piercing, comes the work of polishing, also usually performed by women. The buttons are firmly mounted and polished by a strip of cloth impregnated with highly diluted sulfuric acid and by another covered with tripoli powder. These are passed rapidly over the surface of a turning lathe.

American Methods. The shells are first sorted by hand according to species and quality, then graded as to size by a machine called a classifier. The classified shells are placed into large metal tanks or vats, or sometimes into barrels, in which they are allowed to soak for a week or more, thus becoming soft enough for cutting.

The blanks are cut by means of a lathe fitted with a tubular saw, wooden plug, and ratchet handle or lever; the latter gradually forces the rough shell against the rapidly rotating saw. The waste shell is crushed and used for such things as stucco, fish bowls, and grit for chickens. The blanks are classified by a machine consisting of variously spaced rollers and are thus separated into different lots according to thickness. They are placed in heavy slowly revolving tumblers and

washed with water and pumice stone or sand. Then they are ground on an emery wheel to remove horny backs and provide a uniform thickness. Finally, they are again soaked in water which softens them for the finishing machine.

The more modern factories use an automatic machine which rounds the edges of the buttons, carves out the center in the desired pattern for the face, and drills

FIG. 8–5. Sorting or grading finished buttons.

(Courtesy American Pearl Button Co.)

2 or 4 holes according to pattern. These machines finish from 30 to 70 buttons a minute, thus making from 100 to 190 gross per day.

The drilled buttons are again placed in churns and cleaned with water and pumice in preparation for the final polish. This latter is a tumbling process in which sulfuric acid or other acid is used in conjunction with steam. Finally, the buttons are carefully sorted into 12 grades, and those intended for retail trade sewed on cards.

Manufacture of Inlaid Objects

Because it is at the same time hard and splintery, mother-of-pearl is difficult to process. The initial operation consists of freeing the shells from the outer covering, or "bark." This can be done either before or after they have been divided into separate pieces for ornamental use. In button manufacture the outer coating is usually removed afterwards, while in other cases it is removed before the shell is cut up.

In separating the shells into sections care is taken to secure pieces of good quality and adequate size; only after long practice does the workman acquire the art of doing this properly. The cutting is done with a circular saw of well-tempered steel, the operation facilitated by the use of emery. After the pieces have been cut perpendicular to the surface, it may be necessary to divide them horizontally into thin plates; however, these are more usually secured from the thinner parts of the shell near the lip, while thicker pieces are obtained from that part which is near the hinge. Since the thickness of the nacreous stratum varies in

the different species of shells, it is safer to secure the thin sections directly rather than to risk the operation of horizontal divisions of the thicker sections.

The pieces of mother-of-pearl thus obtained are not entirely smooth, nor are the under and upper surfaces absolutely parallel, owing to the curvature of the shell. As a general rule that side of the mother-of-pearl from which the outer crust has been removed is superior in color to the interior side; but, frequently it is defaced by the existence of cavities.

After the surface of the sections cut out of the shell have been freed of "bark" and polished, they are formed by means of a lathe. This method resembles that employed for ivory and bone. The velocity of the wheel must be carefully regulated, for if it revolves very rapidly there is risk of splitting the mother-of-pearl; to preclude the danger of overheating, the material is kept moistened with water during the turning operation.

For the more artistic inlays, as ivory or tortoise shell, it becomes necessary to pierce the design on thin mother-of-pearl plaque. The design, having been executed, an imprint of it, or more often the design itself, is glued on the piece of mother-of-pearl. This is now firmly set in a screw vice attached to the turning-lathe and carefully cut out by fine steel saws. Here again it is essential to keep the mother-of-pearl moistened, to regulate the speed of the lathe, and to apply a slight coating of fine wax to the saw. For the more delicate touches the burin must be used to supplement the work of the fine saw.

At one time inlaying in mother-of-pearl was practiced to great perfection in Ahmedabad, India. Examples of this work were to be seen on the wooden canopies over the shrines of Shah Alam at Sarkhej and on stone in the marble tomb of one of Sultan Ahmed's queens. The simpler designs were made by filing mother-of-pearl to the required size and then inserting them into a pattern cut into the block of wood. To secure more varied effects pieces of different colors were worked into cement and attached to the surface which was to be ornamented. The commoner sort of inlaying was still occasionally employed for the adornment of the frames of musical instruments.

Cameos

Mother-of-pearl is also extensively carved into cameos. This art is practiced chiefly in Italy, where the chief center is Torre del Greco, near Naples. The shells most commonly employed are of the genus *Cassis*, which is chiefly obtained from the Caribbean Sea and Indian Ocean.

Usually oval in outline, shell cameos are essentially bas-relief carvings in the white outer layer of a conch shell, utilizing the colored inner layer as background. While the classical feminine head is the most common subject, figurines or scenes are more highly valued because of the greater skill required in their carving. Cameos are made in standard sizes from 10 to 60 mm (measured on the long axis) to facilitate mounting as earrings, rings, bracelets, pendants, and brooches.

Types of conch shells from which cameos may be made include the cornelian, sardonyx, and pink. The last two are found mainly in the Caribbean area. The demand for sardonyx cameos, which have a background color varying from grayish brown to sepia, is not now sufficient to attract large supplies of shells; while the pink shade has almost disappeared from use in the past generation, due possibly to its tendency to fade. Practically all cameos made in Torre del Greco

utilize the cornelian shell, which has a background color similar to coral and comes chiefly from Madagascar and Mozambique. Cornelian shells from Zanzibar, according to the local trade, are of poorer quality.

According to Hilliker (1948) conch shells must be of the heavier "male" type, weighing from 400 to 600 or 700 g per shell, to be most suitable for cameo carving. "Female" and "neuter" shells have a thinner "white" layer and are used

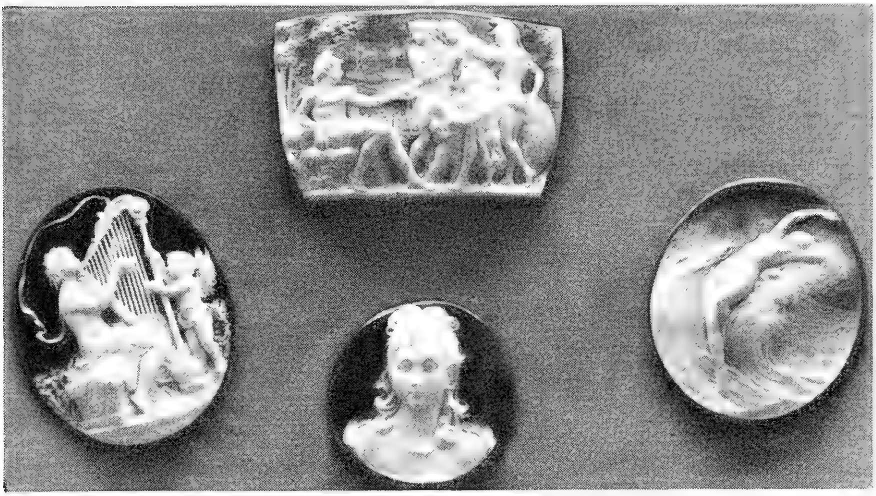


FIG. 8–6. Four mother-of-pearl cameos. (From "The Cameo, Shell and Coral Industry in Naples Province," by G. G. Hilliker, American Vice-Consul, Naples, Italy.)

only for novelty lamp shades and small cameos. In general each shell of the "male" type yields first and second quality cameos, totaling about 65 mm, and third and fourth quality, totaling about 40 mm. Only one first quality piece of from 20 to 40 mm is usually available from the part called the "capo testa" (top of the head) of the shell; while second quality is to be found in a slightly larger area directly below, the "pancia" (stomach).

Production. Not only is the entire shell and coral industry in Naples and vicinity on a handicraft basis, but cameo production is, in addition, carried on largely at home. Whole families participate in carving from raw shells or pieces supplied by jobbers. This arrangement is possible in cameo carving because the raw shells do not have the intrinsic value of raw coral or tortoise shell. The cost of the raw conch shells (landed in Naples) represents an average of only 20 to 30 per cent of the wholesale cost of finished cameos. It is estimated that about 2,000 adult workers in the Naples area are presently engaged in cameo carving, or, including all workers irrespective of age, as many as 6000. Very few cameo factories exist and the principal factory employs as many or more artisans who work at home as those who work on the premises.

The cameo trade is subject both to the unpredictable extremes of jewelry fashion and to all the intricacies of foreign trade. Not only must the raw shells be imported from abroad, but it is estimated that 90 per cent of the cameos produced are exported directly. Most of the remainder are normally sold to foreign tourists

and are thus exported indirectly. Italian cameos are exported to many different countries, among which the United States and the United Kingdom have traditionally been of primary importance.

Jewelry and Miscellaneous Objects

Mother-of-pearl finds use in the manufacture and ornamentation of a great variety of objects for household and personal adornment. Many of the very finest grades are made into knife handles, opera glasses, umbrellas, etc. It is often used for the decoration of fountain pens, clocks, ink wells, picture frames, and other valuable things. Jewelers use it for the manufacture of belt buckles, combs, bar pins, beads, studs, cuff links, hat pins, etc. The pearl obtained from abalones is a favorite.

Mother-of-pearl is sometimes employed to produce a coarse variety of mosaic, called *nacré chinois* in France. It imparts an iridescent sheen to metal surfaces and is used in Naples for iron bedsteads. The design, having been drawn in varnish on the iron, the iridescence is imparted by attaching, with the same varnish that is used to render the design brilliant, very thin layers of mother-of-pearl. In Japan similar, but more carefully executed, work is done on lacquer and the interior surface is lined with layers of pearl or coatings of pearl powder, forming designs of flowers, fruits, etc.

In India the chank shell is held sacred by the Hindus and is utilized in a great number of curious ways. In Bengal every married woman of all thoroughly Hinduized castes possesses a pair of chank bangles (bracelets) lacquered in vermilion as a visible token of her married state. In many other parts of India chank bangles are worn to designate the caste to which the wearer belongs. Chanks are used in many religious ceremonies, including marriage and death rites, and also medicinally for the treatment of a number of diseases.

Preservation

Mother-of-pearl beads and other objects sometimes become soiled or lose their luster. In many cases they may be cleaned by the use of a soapy warm water solution to which a few drops of ammonia have been added. If, however, the beads become stained, they can scarcely be restored; but, if they have merely become roughened, or have lost their lustre, they may be repolished with a paste of dilute sulfuric acid * the polishing being done with a circular felt buffer or a hand buff. If the beads are strung when the ammonia water is applied, each bead should be wiped off with a bit of chamois or tissue paper that has been dipped in the cleansing solution. If, however, they have not been cleaned for a long time, a regular crust may have formed over them. As much as possible of this should be carefully scraped off before the ammonia water is applied.

Blister Pearls

Origin

The term "blister pearls" is used for those which develop on the shell of the pearl oyster. They owe their origin to the defensive or protective action of the mollusk in resisting the intrusion of some animal, such as, for instance, a boring

* *Caution:* Never try to clean gem pearls with these solutions. Use only C.P. grade carbon tetrachloride and wipe dry with a soft cloth.

sponge or burrowing worm which has begun to penetrate the outer layers of the shell, or the intrusion and presence of grains of sand or similar material between the mantle and the shell. To allay the irritation the mollusk deposits nacreous material upon the spot. This accumulation forms a little mound which conforms to the shape of the irritating object and closely resembles a segment of a large pearl. In some cases it results from the mollusk covering a choice pearl which has become loosened from the soft tissues and adheres to the shell and which may be secured by breaking the blister.

The blister pearls found on the abalone shell are formed chiefly in defense of the invading, boring mollusk *Pholadidea parva*. They occur mostly in the red abalone, with only one blister pearl in about 1000 shells of the green or black species. A crab, which infests the abalone at certain seasons, may be the cause of such formations. Frequently, the blister pearls are found over sea urchin spines, chiton, or razor clam shells, pebbles, and other foreign bodies retained beneath the surface of the mantle. Sometimes a diseased visceral lump is cut off and covered by nacre, making a huge blister pearl.

Although pearl blisters appear empty, they are usually filled with some fluid resulting from animal and vegetable decomposition. When a pearl shell shows any protuberance on the surface, the peeler will cut or scrape away a portion of the decaying shell behind the spot. If he finds it to be perfect, and not the hole of a boring insect, this proves that the protuberance has been forced out from within. The pearl is then removed by breaking the shell or by cutting around the protuberance very near its edge. Layer after layer of the covering mass is removed with the greatest possible care.

Closely resembling the "blister pearls" are those known as *bouton* pearls. In this case the pearl-forming sac becomes ruptured and a pearl growing in the tissue of the mollusk, very near the nacreous lining of the shell, gradually becomes attached to the shell. The growth of the under side is arrested, while on the upper, exposed surface further coatings of nacre are deposited. This results in the formation of a "button"; the constantly growing shell finally encloses the pearl, which in some cases is forced backward until it is pushed through and out of the shell. From this source are derived great numbers of half and quarter pearls, which are usually faulty and of indifferent luster.

While the chemical composition of these pearls is the same as that of those regularly found in the mollusk, the physical properties differ to a certain extent. The nacreous layers in the true blister pearls lack the regular concentric disposition characteristic of spherical pearls, and the same holds true for the outer layers of the encrusted pearls.

Utilization

In America the only important source of blister pearls is the abalone shells.

Blister pearls are utilized in jewelry in many ways. Beautiful pins and brooches are made from them. The finest are often mounted in rings. Blister pearl cuff links are much in vogue.

These pearls have been worked into fantastic figures using pearls and other jewels for parts of the designs. Some of the most beautiful designs are to be seen in the famous Green Vaults' Collection in Dresden. One of the most curious is the figure of a dwarf formed of a baroque pearl, studded with small diamonds.

REFERENCES

Allan, J., "The Trochus," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **6,** No. 2, 20–21, 23 (1947).

Anon., "Pearl-Shell Manufacture. Possibility of Secondary Industry," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **5,** No. 3, 6–7 (1946).

Anon., "The Economics of the Pearl-Shell, Trochus, and Bêche-de-Mer Fisheries," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **5,** No. 3, 8 (1946).

Anon., "Sources of Pearl-Shell," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **5,** No. 3, 9 (1946).

Anon., "Pearl-Shell Take Was 803 Tons," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **7,** No. 2, 21 (1948).

Anon., "Pearling Again at Darwin," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **7,** No. 3, 7 (1948).

Anon., "The Romance of Pearl Buttons and Their Manufacture into 'Lady Washington' Pearl Buttons," Washington, Iowa, Booklet published by American Pearl Button Co.

Anon., "Pearl Shell Take Up 46 Per Cent on 1947," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **8,** No. 1, 9 (1949).

Bonnot, Paul, "The Abalones of California," *California Fish and Game,* **34,** No. 4, 141–169 (1948).

Carter, N. M., "Mother-of-Pearl Products Manufactured in Mie Prefecture, Japan," Memo. to Natural Resources Section, General Headquarters, Supreme Commander for the Allied Powers, October 17, 1946.

Clement, L., and Riviere, C., "Synthetic Mother-of-Pearl," *Compt. rend.,* **174,** 1353–56 (1922).

Clement, L., and Riviere, C., "The Synthesis of Mother-of-Pearl," *Chemie et industrie,* **8,** 782–784 (1922).

Ferracciu, R., "The Royal School of Coral Engraving and Fine Decorative Arts of Torre del Greco," Firenze, Italy, 1941.

Hilliker, G. G., "The Cameo, Shell and Coral Industry in Naples Province," Unclassified Report No. 22, Naples, Italy, American Consul General, Sept. 8, 1948.

Jennison, A., "Labor in the Australian Pearl-Shell Fisheries," Australian Commonwealth Fisheries Office, *Fisheries Newsletter,* **5,** No. 3, 4–5 (1946).

Moorhouse, F. W., "Notes on *Trochus niloticus,*" British Museum (Natural History) Great Barrier Reef Expedition, 1928–29, *Scientific Reports,* **3,** No. 5, 145–155 (1932).

Nichols, A. G., "On the Breeding and Growth Rate of the Black-Lip Pearl Oyster (*Pinctada margaritifera*)," Great Barrier Reef Committee (Brisbane), *Reports,* **3,** No. 2, 27–31 (1931).

Pfund, A. H., "The Colors of Mother-of-Pearl," *J. Frank. Inst.,* **183,** 453–464 (1917).

Smith, R. O., "Survey of the Fisheries of the Former Japanese Mandated Islands," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **273** (1947).

CHAPTER 9

The Precious Coral Industry

History

The use of coral for personal adornment goes back at least as far as the third century B.C. for it was described by the Greek philosopher and naturalist, Theophrastus. In Roman times the finest coral was taken in the Mediterranean near the present Hyères and Lipari Islands and off the coast of Trapani in Sicily. Coral and amber were highly prized by the ancient Gauls and extensively used in jewelry. In ancient and medieval times coral was considered to be one of the precious stones. The Romans had many superstitions about coral, believing that it had such beneficial medicinal effects as cooling the human blood, reducing inflammation, etc.

Importance of Industry

Prior to 1900 most commercial coral came from the Mediterranean Sea, being brought into Naples, Messina, Genoa, and Leghorn by Italian boats. Since it can be obtained more cheaply in Japan than in the Mediterranean, coral fishing in Italian waters has slowly died out and is of minor importance today.

According to the U. S. Department of Commerce Italy's imports of crude coral in 1948 totaled 1,827 kg, compared with 11,369 kg in 1938, 7,831 of which came from Japan. Italy's exports of coral manufactures (unmounted) in 1948 were valued at 22,847,000 lire (575 lire to the U. S. dollar); 4,393,000 went to India and Pakistan, 4,784,000 to British West Africa, and 2,143,000 to the United States. Exports of coral manufactures (mounted) totaled 5,537,000 lire (635,000 to the U. S.). Total exports of crude coral amounted to 16,997 kilos, of which 4,497 went to India and Pakistan. The destination of the remainder was not specified in the statistics.

In 1940 approximately 27,600 pounds of raw coral, valued at approximately $300,000, were obtained from Japanese waters. The production of Formosa and the Pescadores Islands came to about 4,000,000 pounds, valued at about $350,000. Since these waters are outside the fishing areas authorized by the occupational authorities, no considerable quantity of precious coral has been fished in Japan since World War II.

Nature of Coral

Living Coral. It was formerly believed that coral belonged to the plant kingdom and was a peculiar kind of seaweed. Modern biologists have found, however, that it resembles plants in form only, and that a single, complete branch bears a great number of organisms, the polyps, which form a sort of colony. During the life of these animals the red calcareous material of the branch is covered with a

thin, fleshy, reddish rind, termed the coenenchyma, in which the polyps are embedded. They are easily distinguished by their white hue, and secrete a lime which serves to build up the structure of the branch. These branches do not seek the light as plants do, but spread horizontally along the bases to which they are firmly attached. The fleshy rind covers the entire coral up to the ends of the branches, which are therefore soft and pliable and can be severed with a sharp knife. If a living coral-branch is allowed to dry in the air, the skin, or brick-red rind, hardens, and little protuberances, containing the polyps, appear. These protuberances have a round aperture in the center from which 8 short ridges ray out.

The greater part of the coral-producing organisms belong to the actinozoan division of the *Coelenterata,* with the exception of the hydrozoan staghorn coral (*Millepora alcicornis*) and its congeners. There are two divisions of the coral-producing actinozoa: namely, the *Octocoralla,* in which the animal is 8-rayed, and the *Hexacoralla,* or 6-rayed animal. The first-named class comprehends the "sea fans" and "sea whips", *Gorgonia* and *Muricea,* of the southern coast of the United States and the precious coral of the Mediterranean region.

The Coral of Commerce. The specific gravity of coral, ranging from 2.6 to 2.7, closely approaches that of calcite, but its hardness, 3.75, is a little greater owing to slightly different composition. This low hardness facilitates the carver's or turner's task. Although coral does not take a fine polish, its beauty of hue compensates for it; although not very hard, the material has toughness and tenacity and wears well. As it is slightly opaque, scratches do not show. Since it is composed chiefly of calcium and magnesium carbonates, acidulous perspiration affects its surface.

The composition of red and black coral is indicated in Table 23.

TABLE 23. COMPOSITION OF PRECIOUS CORAL

	Red Coral	Black Coral
Calcium carbonate	86.974	85.801
Magnesium carbonate	6.804	6.770
Calcium sulfate	1.271	1.400
Ferrous oxide	1.720	0.800
Organic matter	1.350	3.070
Water	0.550	0.600
Phosphoric acid (P_2O_5), Silica (SiO_2), etc.	1.331	1.559
	100.000	100.000

From these analyses it appears that black coral differs from red chiefly in organic content. Various observers have concluded that the color of the black coral is due to the presence of organic matter. It has been assumed that the red color of precious coral is caused by its iron content; however, the latter conclusion does not seem probable as the red color is destroyed on ignition. The red coloring matter is presumably an organic compound formed by the polyps.

Location of Fisheries

Mediterranean Fisheries. The most important and profitable coral banks in the Mediterranean are on the Algerian and Tunisian coasts. The former extend eastward from Cape Ferro (Cap de Fer) toward Cape Bon, and in a southerly direc-

tion to the Gulf of Gabes in the region of Sfax. The coral fisheries are carried on at 6 or even 8 miles from shore and at depths between 90 and 900 feet. It has been found that coral taken from considerable depths is paler and less lustrous than that from lesser depths. In these regions the fisheries have been carried on for centuries. In former times the assembling place was the island of Tabarca. Even today this island and the island of Galita are still frequented by coral fishermen; but the most important station is the coast town La Calle, where much has been done by the French Government to further the industry. Other centers are situated on Cap de Garde and Cap de Fer and at Sidi Mansur, opposite the Kerkennah Islands in the Gulf of Gabes.

There are coral banks, rivalling those of Algeria and Tunis, on the coast of Sicily. The most productive for the past 50 years have been located near Sciacca, west of Girgenti. Their average depth is about 650 feet. A curious characteristic of these banks is that all the coral polyps are dead and, as a result, many of the corals have lost their fine red color.

Coral is also found off the small islands north of Sicily, Ustica and the Lipari; but a more important coral fishery is in the Strait of Messina. However, the chief center of coral production, after the North African Coast, is located off the western side of Sardinia and Corsica. The richest field is the Strait of Bonifacio between the two islands.

Off Jedda in the Red Sea there is a black coral fishery extending for 50 miles north and south. This black coral is carved into beads and mouthpieces for cigar holders. As the dull white coral is less hard than the black and does not take a good polish, it is sold cheaper.

Japanese Fisheries. Although the Japanese coral fisheries have not been worked since the beginning of World War II, they are the most important in the world. The four main Japanese coral-fishing grounds are: (1) The southern sea areas immediately around Imoto-Jima in the Central Bonins and Tori-shima in the northern Bonins. (2) The sea areas off Kochi Prefecture, Shikoku. (3) The sea areas around Danjo Island, west of Kago-shima Prefecture, Kyushu. (4) The sea areas immediately around the Pescadores, west of Formosa.

American Fisheries. Recently a large amount of rare violet coral has been discovered a few miles off the coast of Southern California. As this coral is in deep water where there are currents, its collection by divers is rather hazardous. It is more comparable to precious coral than to the cheap, dyed variety, such as that exported from the Philippine Islands. However, the development of the industry in California has been retarded by lack of trained coral engravers.

Methods of Fishing

Mediterranean Methods. The coral fishery is usually carried on during the 6 months of spring and summer although in some regions it continues throughout the year. The boats used may collect from 600 to 650 pounds of coral in a season. Solidly constructed and seaworthy, they commonly range in size from 6 to 16 tons and are manned by a crew of 6 to 12. Most of the boats are owned by Italians and bear the product to Messina, Genoa, Leghorn, and Naples, where it is bought by carvers and jewelers. A certain number of smaller boats, of from only 3 to 6 tons, sail under the French flag; but the crews are almost entirely composed of Italians. These boats remain busy the greater part of the year.

Some coral is collected by divers working from small boats near the shore where the water is not over 10 feet deep; but the largest and most beautiful coral grows in much deeper water and is inaccessible even to fully equipped divers. To obtain it the coral fisheries of the Mediterranean use a specially constructed instrument, called "ingegno" by the Italians, "engin" by the French. It consists of two crosspieces of solid oak, the length, varying with the size of the fishing boat, from 1 to 2½ meters, or even more. The two pieces are firmly bound together in the middle so as to form four long tapering arms. At the point of contact is attached a heavy object which causes the "engine" to sink in the water. Each of the four arms is encircled by a groove along which passes a rope from 6 to 8 yards long, one end of which is fastened. At the intersection of the arms is attached a fifth and still longer rope. To these ropes are bound at regular intervals the actual implements for seizing the coral. These are very coarse-woven, square nets, with a mesh, several centimeters wide, made of loosely twisted hemp-twine as thick as a finger. In all there may be from 30 to 40 such nets on a machine. Alongside the coarse-meshed nets hangs one of finer mesh, commonly made from the old nets used in sardine fishing. The machine, which is fastened to the bark by a long cable, is cast into the water and the nets spread out. The weight of the machine carries them down to the bottom and the pieces of coral and other material become entangled in the meshes. Considerable time is needed for operating the machines and, as a rule, the process of sinking, raising, and cleaning out the nets can only be repeated 6 or 7 times in the course of a day.

Japanese Methods. In Japan coral is found chiefly in the southwestern waters affected by the warm current. Here it grows on rocks 30 to 100 fathoms under the surface. Small boats, manned by 3 or 4 men, are used. A very simple, strong net, about 5½ by 6 feet, is attached to a 6-foot bamboo pole. At each end of the pole is a small net of ropes, 5 fathoms long, under which 10 similar nets are hung by means of 5-foot ropes. Below the 10 nets 3 nets are hung by means of brass wire and 7-fathom ropes. Each of these nets has a stone weight of 1½ pounds. A 2½ pound stone is attached to the middle of the bamboo pole, to which are tied 4 ropes, each 7 feet long; this device keeps the nets in equilibrium when tied together and dragged over the bottom by a rope 100 or more fathoms in length. When the nets are drawn over the coral reefs, the first net brushes the coral off the rocks and the other nets catch it and bring it to the surface.

Grading of Coral

Coral, as it is obtained by fishermen, is called rough coral. Before it is marketed, it is sorted into the following grades:

Dead or Rotten Coral. This consists chiefly of the lower portion of the main stem and the disklike "foot" of the coral stock. When the outer crust is removed, valuable pieces of coral are often found. Often the broad footplates are worked into small dishes and bowls.

Black Coral. This includes coral in which the black color extends through the whole or a large part of its substance.

Common Red. Red coral of all kinds, with the exception of pieces of exceptional size, are placed in this class. It embraces alike whole stocks and broken fragments irrespective of form and size.

Selected Pieces. Pieces of exceptional size or beauty are selected from the ordinary red coral and bring very high prices.

The Working of Coral

The working of coral into ornamental objects is done mainly by Italian craftsmen. The industry is also carried on, though much less actively, in Spain and France. It has been estimated that in Italy before World War II there were some

FIG. 9–1. Torre del Greco cameo factory. (From "The Cameo, Shell and Coral Industry in Naples Province," by G. G. Hilliker, American Vice-Consul, Naples, Italy.)

600 establishments for this work and the carving of conch and other shells, employing about 6,000 men and women. In this industry, as well as the coral fishery, Torre del Greco occupies the most prominent place, for here alone there are counted as many as 40 workshops with 2,000 women and 400 men employed. The carving of shell cameos is actually the principal industry in many of these small factories (p. 136). The industry is carried on to a lesser extent in Genoa, Naples, Leghorn, and Trapani.

The principal use of coral is for beads to be strung as necklaces, bracelets, armbands, or rosaries. The beads are made either spherical or oval; toward the beginning of the last century they were frequently faceted, but this has gone out of fashion. The Italian carvers are also very deft in executing little coral cameos, with floral or animal designs and sometimes with human figures. They are very ingenious in utilizing the imperfections of the material to produce striking effects. These objects are often set in the handles of brushes, etc. Polished ends of the coral branches are made into watch charms.

The Royal School for Coral Engraving at Torre del Greco near Naples was

founded by decree on June 23, 1878. Free instruction is given to both day and night classes as to technical and artistic engraving on coral, lava, shells, tortoise shell, ivory, hardwoods, metals, etc. All the necessary material is furnished without charge, but remains the property of the institution. To graduates a good part of their work in designing and decorating is given, as are also some clay models of plastic designs and engravings. The entire course covers 4 years: In the first year the pupil attends preparatory classes in designing; in the second year there is more advanced instruction in designing, as well as an introduction to plastics or engraving and inlaying; in the third year comes the first course of applied design and the second course of plastics or engraving and inlaying; the fourth year is devoted to finishing these different branches.

Utilization in Jewelry

As objects of personal adornment coral beads and other coral ornaments are much more highly favored in the Orient than in the Occident. However, in some parts of Italy, as well as in Poland and the territory of the former Austrian Empire, coral jewelry is much fancied. In Turkey coral is not only used for jewelry, but is inlaid in the decorated walls of rooms and employed freely for many objects, such as pipes, weapons, and the trappings of horses. In North Africa, with the exception of Egypt, where it is not much esteemed, coral enjoys great popularity; this is also the case in Arabia. The Persians esteem it highly and the same is true of the Chinese and Japanese. In India and Tibet it ranks among the best materials for jewelry. In India it is set in necklaces, garters, and amulets and has a religious use as a gift to the dead as it is believed to keep evil spirits away. It has been aptly remarked that a fondness for coral indicates a certain degree of culture in a race. The attempts made by traders to substitute coral beads for glass beads in bartering with savage or semicivilized peoples have not been successful, the "untutored mind" and eye greatly preferring the sheen and sparkle of the vitreous surface.

Jewelry made from pure white Japanese coral has gradually become more popular. White coral in which each bead has a small spot of pink is still appreciated; the most delicate pink tint is also much admired. About 1920 deep red Moro coral came into vogue; plaques of black onyx were set alternately with this coral, thus offering an effective contrast. Earrings of pear-shaped coral and onyx or coral rings hanging from chains of tiny diamonds also became fashionable.

REFERENCES

Anon., "Japan's Prewar Coral Industry," Natural Resources Section, General Headquarters Supreme Commander for the Allied Powers, *Weekly Summary*, No. 122, 10–13 (Feb. 8–14, 1948).

Ferracciu, R., "The Royal School of Coral Engraving and Fine Decorative Arts of Torre del Greco," Firenze, Italy, 1941.

Hilliker, G. G., "The Cameo, Shell, and Coral Industry in Naples Province," Naples, Italy, Unclassified Report No. 22 American Consulate General, Sept. 8, 1948.

Tressler, D. K., "The Wealth of the Sea," New York, Appleton-Century-Crofts Inc., 1927.

CHAPTER 10

Characteristics of Marine Fishes

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Definition

Many kinds of animals that have little in common, except a water habitat, are called fish. Some of these are very low forms of animal life, as for example jellyfish, which are composed of a jellylike mass and have no hard (bony) parts. The sponges, which are also a low form of animal life, are generally listed with the fishes in statistical reports and the means of procuring them is referred to as the "sponge fishery". Shellfish consist of both mollusks and crustaceans: the former are mostly oysters, clams, and scallops; the latter includes shrimps, crabs, lobsters, and crawfish. Structurally these forms are all far removed from those that provide the basis for the accounts that follow. Whales and porpoises are an exception to this definition: they are not true fishes but warm-blooded mammals.

These animals are commonly referred to in technical works as fish and fishlike vertebrates. They may be defined as cold-blooded animals, having a backbone (which is cartilaginous in the lower groups) and, with few exceptions, limbs or rudiments of limbs represented by fins. They live in water, wherein they breathe by means of gills. Although the skin may be naked, it is usually covered with scales, denticles, bony plates, spines, or tubercles.

The lowest forms of animals considered in these pages are not fish, but only fishlike animals. They are the lancelets, *Leptocardii,* and the lampreys, *Cyclostomi.* That great group of animals, which meets all the requirements of the definition of a fish offered in the preceding paragraph, may be divided into two main groups: namely, the sharks, skates and rays, and chimaeras, *Selachii,* and so-called true fishes, *Pisces.* The *Selachii* have cartilaginous skeletons, whereas the *Pisces,* with few exceptions, have bony skeletons. These several groups of fish and fishlike animals will be discussed in more detail subsequently.

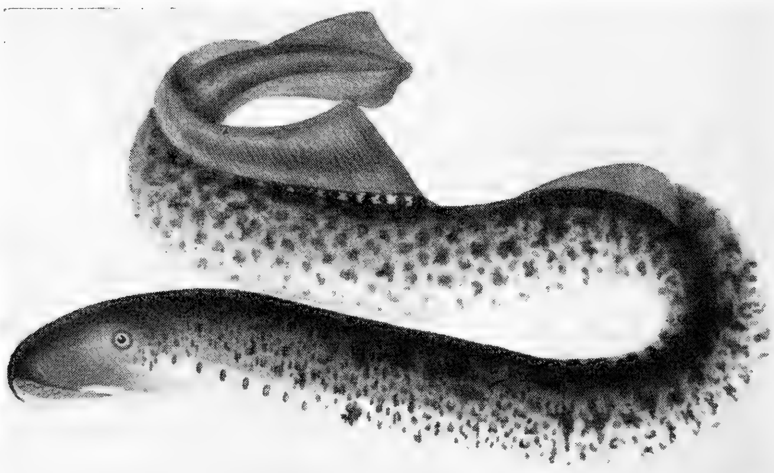
The Antiquity of Fishes

The first animal with a backbone was a fish. Its ancestor, it is believed, was a marine creature that incased its spinal cord in a hard protective covering, which gave its body rigidity and suppleness. A group of small marine animals exists today that probably resembles rather closely this primitive ancestor, which lived many millions of years ago. These small living animals, which attain a length of only a few inches, are the lancelets, also known as amphioxus. These are listed in the classification of fishes and fishlike animals as the *Leptocardii.* The lancelets

* Deceased.

have no vertebrae, as their "backbone" consists of a continuous cartilaginous rod. Neither do they have jaws, the mouth being a mere lengthwise slit. The median fins, that is, the dorsal, caudal, and anal, are composed of continuous membranes without rays. Paired fins, or limbs, are entirely missing.

The next higher group of fishlike creatures are the lampreys and hagfish (Fig. 10–1). These animals are known to the scientist as the *Cyclostomi.* Although they, too, are primitive forms they do represent a forward step in development from the lancelets. They are eel-like or wormlike in shape and have a fairly well-



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–1. The great sea lamprey. (*Petromyzon marinus.*)

developed, though continuous, spinal column. They have an imperfectly developed skull, heart, and brain. They still have no jaws and no paired fins representing the limbs of the higher vertebrates. The mouth is round or oval, forming a suctorial disk, and is generally provided with rasping teeth, which are their only hard (bony) parts, the skeleton being cartilaginous as in the lancelets.

Cyclostomes attach themselves with their suctorial mouths to their hosts, generally larger fishes, and eventually bore with their teeth into the abdominal cavity or vital parts, causing the hosts to die. In some areas the lampreys are highly destructive of other fish. However, some of them reach a length of about 3 feet and become food fishes of slight importance.

The primitive forms already mentioned have not been found in the rocks probably because they had no real bones or spines, and, therefore, no part of them became fossilized.

The next higher group of animals are the sharks and skates and rays. Although their skeletons, too, are cartilaginous, they have a spinal column composed of vertebrae. They have jaws, though the upper one is attached to the skull, definitely developed paired fins, and well-developed gills. Therefore, they meet all the requirements of the definition of a fish offered near the beginning of this section.

Some students are of the opinion that sharks are the most primitive of existing fishes. Indeed, some fragments, particularly spines, occur in rocks at an early period. However, the first remains that are definitely identifiable as those of a shark occur in the Carboniferous period. These oldest primitive sharks were small, probably only 2 to 6 feet long. The skin was covered with hard bony points (denticles), and the teeth had a large central cusp and a broad base with smaller cusps, almost exactly as in some modern sharks. Other sharks succeeded those of the Carboniferous period, but nearly all the old forms perished. One family, the bullhead sharks (*Heterodontidae*), however, survived. At least 4 species of bullhead sharks exist today; they are small, generally only a few feet long, and like other primitive sharks have a spine in front of each of the two dorsal fins they bear.

During the Eocene and Miocene periods the warmer oceans teemed with sharks if one may judge from the abundance of teeth that have been found. Some of these more recent sharks, too, were small, but others were giants. It has been estimated, chiefly from the size of their teeth, some of which are 3, 4, and even 5 inches long, that certain species among these primitive sharks attained a length of about 120 feet. By comparison the largest living one, the whale shark (*Rhincodon typus*), which attains a length of about 45 feet, is almost a pigmy.

Another group of primitive fishes that has survived are the chimaeroids (*Chimaeridae*), which are sharklike in character. Remains of these animals appear early in geologic time, certainly as early as the middle Silurian period, and therefore much earlier than the remains definitely identified with the sharks. The several living forms, generally only about 1 to 2 feet long, are variously known as spookfish, ratfish, and elephant fish. These animals, too, have a cartilaginous skeleton, but they have a strong bony spine in front of the dorsal fin and heavy platelike teeth. The remains in the rocks, of course, consist of these hard parts.

However, remains of more primitive fishes than the ancestors of the living forms already mentioned are known. In fact the earliest ones date back to the Paleozoic period or almost to the beginning of life on earth. The time in years, of course, is not known. One writer has estimated it at 400 million years. These very old remains unfortunately are so fragmentary that it has not been possible to determine what the fish were like.

The earliest recognizable fish remains are those of the ostracoderms, so-called because of the dorsal and ventral dermal plates that covered the head and anterior part of the body. The posterior part of the body was usually covered with small plates or scales. The ostracoderms and their similar species first appeared in the Silurian, apparently became abundant in the Devonian, and shortly became extinct.

The small ostracoderms were followed by the much larger arthrodires, which attained a length of about 10 to 18 feet. These fish also were armored anteriorly, but the armor was not continuous, for there was a hinge at the neck so that the fish could bend their heads. Furthermore, the arthrodires possessed large powerful jaws and small pelvic limbs. These characteristics may have made them rulers of the sea for a time. However, despite their armor, large mouth, and formidable size they eventually became extinct, and left no near relatives.

The higher groups, or true fishes, *Pisces,* also called *Teleostomi* left more of their remains in the rocks than the cartilaginous fishes because their skeletons

were at least partly ossified (bony) and these hard parts became fossilized more readily. The true fishes, in addition to the vertebral column, have hard skulls; unlike sharks the upper jaw is not attached directly to the skull, but is joined with intermediate bones. There are so-called membrane bones, such as the opercle and subopercle, about the head, and at least one pair of limbs is more or less developed. Most of the true fishes have an air bladder, and a single opening leads to the gills or branchial chamber. The vast majority of living fishes and a considerable portion of the extinct ones, as already indicated, belong to this class.

The direct ancestors of some of the living Teleostomi appear first in the Devonian formation, sometimes estimated as early as 400,000,000 B.C. These primitive forms include the ganoid group in which the skeleton is not fully ossified. To this group belong the familiar living fresh-water gars, paddlefish, sturgeons, and the somewhat despised bowfin or fresh-water dogfish of our waters. The fringfins of North African rivers and the lungfish of Australia, Africa, and South America also belong to this primitive group. The ganoids were once much more numerous. What caused their decline has not been determined. Certainly, the living forms seem well adapted for carrying on the processes of life under present conditions.

The fossils of teleosts, or "true bones", date back only to the Jurassic period, or perhaps somewhat less than 200,000,000 years. The teleosts, the "youngest" of the major groups of fish, have been regarded as a branch of the early ganoids; now, however, the teleosts greatly outnumber all the other groups of living fishes combined. In general they have a thoroughly ossified, or calcified, skeleton: The backbone seldom enters the upper lobe of the caudal fin, as in the ganoids; the air bladder is very rarely lunglike and generally does not assist in respiration; and the dermal bones of the head, which are at the surface and enamel-coated in the ancestral ganoids, are deep-seated and often covered with skin and scales.

Such, then, in brief, is the origin and the history of fishes, living and fossil. Some of the recent forms have diverged widely from their ancestors, while others have remained fairly stationary. A discussion of the evolutionary processes involved in the changes cannot be given in this short treatise. It can only be said here that every ichthyologist is keenly aware that evolutionary forces are still active.

Anatomy

Form or Shape of Body. Fish vary widely in shape or form. The common Atlantic herring, *Clupea harengus,* may be chosen as an example of the most usual. In this species the body is elongate and somewhat compressed, all lines being curved. This fish serves well as the type of the *usual* fish form, and with it some *unusual* forms will later be compared. Uniformity in shape, however, does not always exist within a family, and certainly not within the herring family, from which the fish with the *usual* form has been selected. There is, for example, the so-called round herring (*Etrumeus sadina*) which is nearly round, or almost cigar-shaped. Other species, although elongate, are excessively compressed (*Odontognathus*). Still another member of the herring family (*Pristigaster martii*), which also is strongly compressed, has a chest and abdomen so greatly expanded that the ventral outline forms an arc.

Many common food fishes are shaped more or less like the Atlantic herring, a

shape often said to be fusiform, that is, elongate, roundish to somewhat compressed, and tapering toward the head and tail. A body with such a shape offers a minimum amount of resistance in proportion to its size in swimming. Boat, airplane, and automobile designers have given careful study to the shape of the swift-swimming fishes, especially mackerel, which are among the fastest and most powerful swimmers and are the most perfectly "streamlined". All fusiform fishes, however, are not swift swimmers, as, for example, codfish, weakfish, common herring, shad, and many others.

Eels, which are true fishes, popular opinion notwithstanding, have departed rather widely from the "usual fish form"—the Atlantic herring—as they are elongate, usually roundish, and snakelike. This shape makes it possible for them to enter small crevices and penetrate dense vegetation. Some eels live habitually in the crevices in coral formation where they await the approach of small fish upon which they feed; others remain in muddy places or open water. Nearly all eels have fair-sized mouths, provided with rather large teeth which are useful in catching prey. At least some eels, as the writer himself has observed, are capable of traveling, snake-fashion, short distances over land.

Spadefish, dollarfish, butterfly fish, and angelfish differ from the "usual fish form" in that they have short, deep, and strongly compressed bodies. In fact, some of them are as deep as they are long. They all have small terminal mouths, most of which contain brushlike teeth suitable for rasping plant growths from rocks, piling, and other submerged objects. The writer has spent some time observing spadefish foraging on algal growths among pier structures, and has seen them feeding in narrow spaces that a broader or thicker fish could not have entered. They apparently do not reject small animals that live among the plant growth. In fact, this writer has enticed spadefish to take a small hook baited with bits of fish flesh and particles of hermit crabs. These deep-bodied fishes are not "built" for rapid swimming like the mackerel, but some of them are capable of making fair headway.

Skates and rays, too, are thin and flat, but in the opposite direction from that of the compressed group discussed in the preceding paragraph. The typical ones are strongly depressed, having very low and broad bodies. Although usually very different in shape, they are related to the sharks. They also have cartilaginous skeletons and possess several slits that lead to the gills. Because of their inferior mouths and the shape of their bodies they are adapted to living on the bottom. Many skates and rays have blunt teeth, arranged in series like the bricks in old pavements. Such teeth are suitable for crushing hard-shelled animals, such as oysters, clams, and other mollusks. Many of them have one to several large sharply serrated spines, inserted on the upper surface at about the midsection of the basal half of their slender, whiplike tails. These spines are dangerous to man as the animals are capable of inflicting serious wounds with them. There are poison glands along the basal part of the spine that secrete a sort of venom. Although the "sting" of these animals—sometimes called "stingerees"—is terribly painful, no deaths definitely attributable to the venom seem to have been reported.

Flatfish, that is, flounders and soles, are also strongly compressed. Oddly enough they do not swim erect, except for a little while during their larval stages; instead, they lie and swim on one side. Like the skates and rays, they dwell chiefly on the bottom, and their underside, like the ventral parts of the skates and

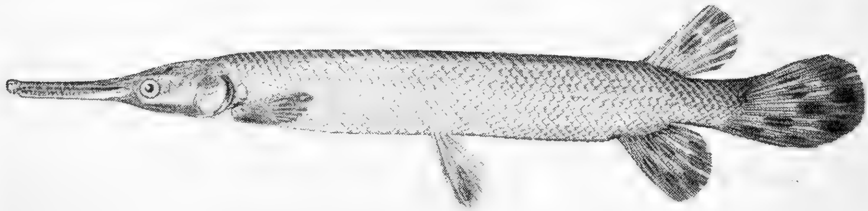
rays, is devoid of color. The upper side is fully pigmented and this is where both eyes are located. The young, for a very brief time while in the larval stages, swim upright and have eyes on opposite sides of their head. But very early in life they turn either to the left or right side, according to the species. During this turning process the eye on the lower side of the head "migrates" to the upper side, twisting the skull in the process. This is a wise provision made by nature, for an eye could not serve a useful purpose when buried in sand and mud. Most species of flounders have fairly large mouths, equipped with moderately well-developed teeth which adapt them to the life of predators.

Finally, we may mention the globular fishes as another form that departs widely from the usual. These fishes include the puffers or blowfish, burrfish, and porcupine fish. They have short roundish bodies and are capable of inflating themselves with water or air, hence becoming globular. As they are not adapted to rapid swimming, they must use their power of inflation for defense, to which further reference is made in another section of this chapter.

Many intermediate forms exist. The deep sea contains many which have a distinctly bizarre appearance: large heads, large mouths, fanglike teeth, small bodies, long tails, excessively large eyes, stalked eyes, etc. Many deep-sea forms have light organs. When those which have light organs turn on all the lights, they must look like a well-lighted ship at sea at night. Then there is the very oddly shaped ocean sunfish which is so short that it looks as if it were all head, with body and tail missing. This fish, which grows to a weight of a ton or more, is so flat and round that it reminded the scientist who named it of a millstone. Accordingly, he called it *Mola mola.*

It is evident from the foregoing paragraphs that fish "come" in many shapes and forms. It is plain, also, that the phrase "shaped like a fish" is not actually descriptive.

The Body Covering. In the discussions relating to the antiquity of fishes and their shape or form body coverings were mentioned incidentally. It was shown



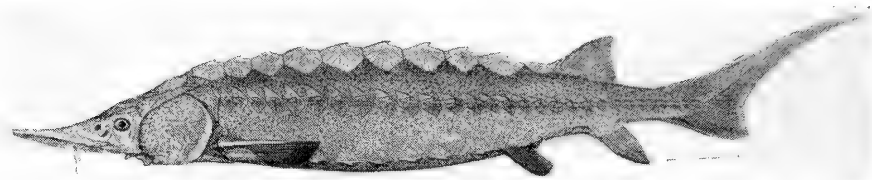
(Courtesy U. S. Fish and Wildlife Service)

Fig. 10–2. Gar (*Cylindresteus platestemus*).

that some of the extinct forms were largely incased in bony shields. One group of living fishes, namely, the ancient fresh-water gars, still retain a fair armor, the head being protected by hard external bones and the body by hard overlapping bony plates (Fig. 10–2). The sturgeons, which, too, are ancient fishes and belong to the ganoid group, have large bony plates in rows that do not cover the body

entirely (Fig. 10–3). Then, there are many catfish, both in fresh and salt water, that are naked. However, these fishes have relatives in South America (*Loricariidae*), many of which are fully armored with bony plates and are sometimes referred to as "hard-shelled catfish".

Sea horses and pipefish, also, have a sort of exoskeleton, composed of bony rings, which allow some flexibility. However, the trunkfish or boxfish have a more

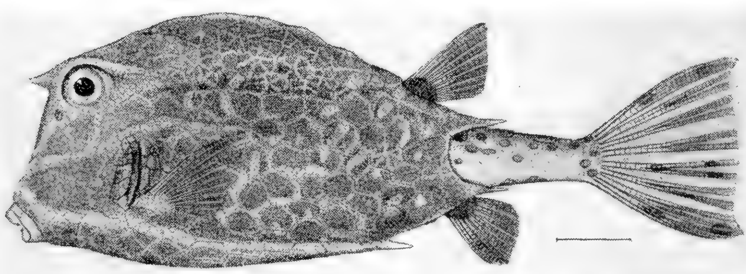


(*Courtesy U. S. Fish and Wildlife Service*)

Fig. 10–3. The common sturgeon (*Acipenser sturio*).

complete armor than the species already mentioned, for their "trunk" encases the entire animal, except the tail. The trunk or box is composed of hard, thoroughly united bony plates, which allow no flexibility. Furthermore, the trunk is generally provided with several large spines. One species, *Lactophrys trigonus,* has a strong, hornlike spine in front of each eye, from which the popular name "cowfish" derives (Fig. 10–4).

Sharks, with few exceptions, have a rough skin, parts of which formerly were used as an abrasive, called "shagreen". This perhaps is the oddest of all fish



(*Courtesy U. S. Fish and Wildlife Service*)

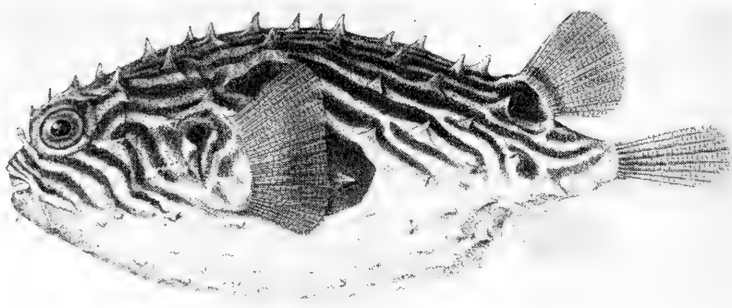
Fig. 10–4. The trunk fish or cow fish (*Ostracion quadricornis*).

coverings, as the roughness is caused by minute "teeth" set in the skin. These small projections are known to the ichthyologist as denticles, which is a proper designation as structurally they are actually teeth. This, then, is an example of an animal virtually covered with teeth.

Skates and rays, though related to the sharks, are wholly or partly naked and do not have denticles set in the skin. Some of the skates and rays have bony spines or bucklers, or both, generally arranged in rows on the back, though in some species they are in patches. The porcupine fish is an outstanding example of fish almost completely covered with long and sharp bony spines, resembling the quills of the mammal from which it derives its common name (Fig. 10–5).

Scales, of course, are by far the most common covering. They vary so much in

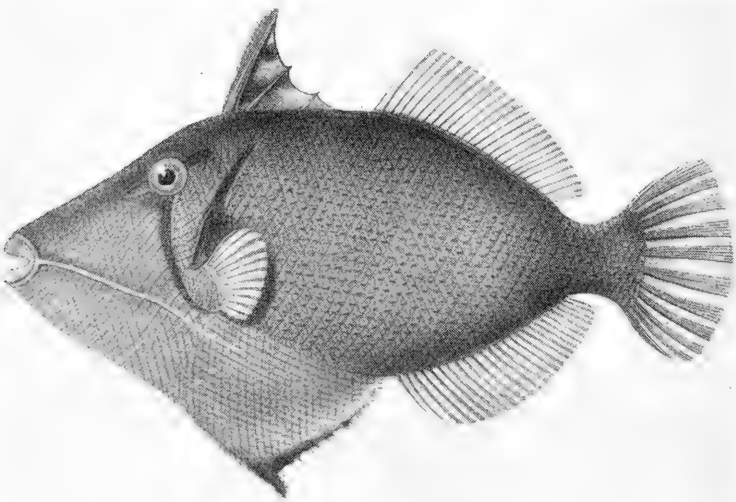
size and structure among the species, however, that they are variously classified. Two main groups of scales—cycloid and ctenoid—are generally recognized. Cycloid scales have smooth, unindented free edges, whereas ctenoid scales have



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–5. The porcupine fish (*Chilomycterus schoeffi*).

rough edges. This division is useful in classifying fishes, even though occasionally scales intermediate in structure and not clearly cycloid or ctenoid are found. Furthermore, some species, like the triggerfish (*Balistes*) have platelike scales (Fig. 10–6). Then, there are elongate, round, and deep scales of various sizes.



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–6. The triggerfish (*Balistes bursa*).

The fresh-water eel is well-covered with small elongate scales placed in patches, the scales in one patch at right angles to those in another. Though embedded in the skin they are visible externally upon close examination. The tarpon, *Tarpon atlanticus,* on the other hand, has very large, overlapping, external scales, which

are cycloid and arranged in regular series. The croakers (*Micropogan*), weakfish (*Cynoscion*), and many others have moderately small ctenoid scales. Scales so small that they are generally overlooked partly cover the mackerels, as, for example, the Spanish mackerel (*Scomberomorus maculstus*). The question, "Do mackerel have scales?", has been answered in the affirmative many times by the Fish and Wildlife Service and the former Bureau of Fisheries. It is true that the scales in some species of mackerel are rudimentary, and in others only the anterior part of the body is covered. However, it is correct to say that the mackerels belong to the "scaly fishes".

The scales of fish are of further interest because their age can be determined, especially in temperate regions where there are definite summer and winter seasons, resulting in periods of rapid and retarded growth. The differences in the rate of growth of the fish is "registered", in its scales, which bear growth rings, called "circulae". When growth progresses slowly, as during the winter, the rings are formed close together, while they are formed farther apart during the summer when rapid growth occurs. Thus, with some practice the student is able to determine the approximate age of many kinds of fish from temperate regions.

The Fins. It was stated near the beginning of this chapter that fish, with few exceptions, have limbs, or at least rudiments of limbs, which are represented by fins. In addition to the paired fins representing arms or legs most fish have median or vertical fins. The pair of fins corresponding to the front legs of higher vertebrates are known as pectoral fins; the pair corresponding to the hind legs are called ventral or pelvic fins; those on the median line of the back, of which there may be 1 to 3, are dorsal fins; the one forming the tail is the caudal fin; and those on the median ventral line behind the vent, of which there may be 1 or 2, are called anal fins. All these fins differ widely in size, shape, and position and the dorsal and anal fins vary in number.

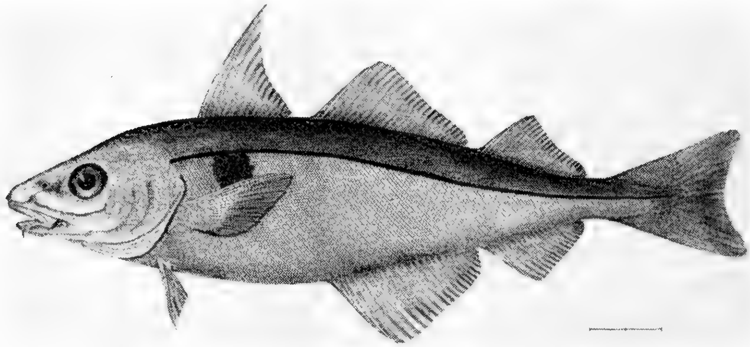
In reference to the fins we may refer again to the common Atlantic herring, *Clupea harengus*, chosen earlier in this chapter as a usual type of fish. The herring has the ventral fins attached to the abdomen, and consequently belongs to a large group of fish known as *Abdomenales*, all of which have these fins similarly attached. Furthermore, the herring has one dorsal and one anal fin. This is quite the usual arrangement among the *Abdomenales*. However, salmon, trout, smelts, and several others have, in addition to the fins possessed by the herring, a small rayless flesh fin behind the dorsal fin. This small fin is known in ichthyology as an "adipose fin."

The greatest number of well-developed fins with several or many rays occurs in some of the members of the codfish family, as well as in the codfish itself, and in pollock and haddock, each of which has 3 dorsal and 2 anal fins (Fig. 10–7). However, the hakes (*Urophycis*), which are classed with the codfish (*Gadidae*), have only 2 dorsal fins, a short and a very long one, and a single long anal fin. Although the codfish rays are all soft and lack true spines, they are not *Abdomenales* as their ventral fins are attached to and in advance of the thorax.

The fins in the vast majority of fishes are composed partly of spines and partly of soft rays. These are the "spiny-rayed fishes". Many of them have the same number of fins as the herring, but some of the fins begin with spines which are followed by soft rays. This is the arrangement in the sea bass (*Centropristes*),

groupers (*Epinephales* and *Mycteroperca*), snappers (*Lutianus*), grunts (*Haemulon*), and many others (Figs. 10–8 through 10–12).

Many spiny-rayed fishes have 2 dorsal fins, however, the first being composed

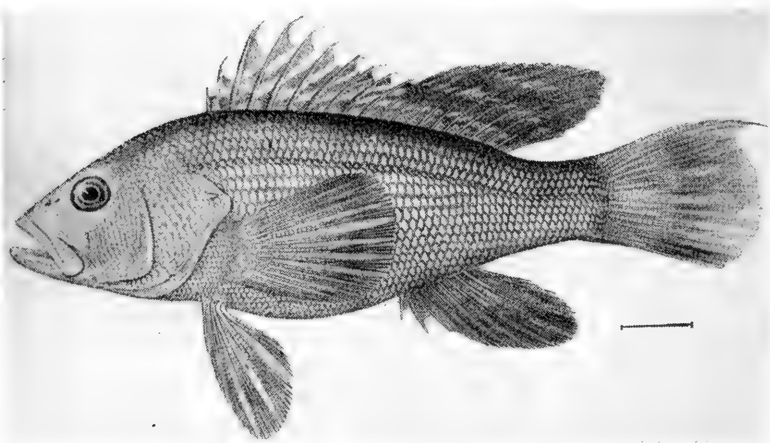


(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–7. Haddock (*Melangogrammus aegelfinus*).

wholly of spines, and the second commonly of 1 spine and a variable number of soft rays. Examples of this type of arrangement are the mullets (*Mugil*), striped bass (*Roccus*), croakers (*Micropogon*), weakfish (*Cynoscion*), etc. (Figs. 10–13 and 10–14).

Still another type of single-rayed fin occurs among some of the spiny-rayed

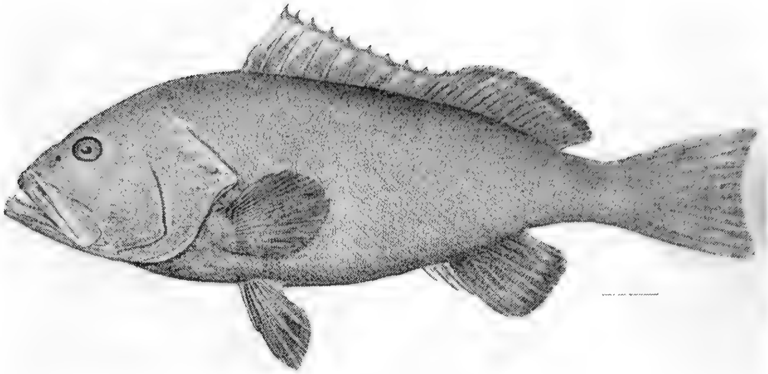


(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–8. Sea bass (*Centropristes striatus*).

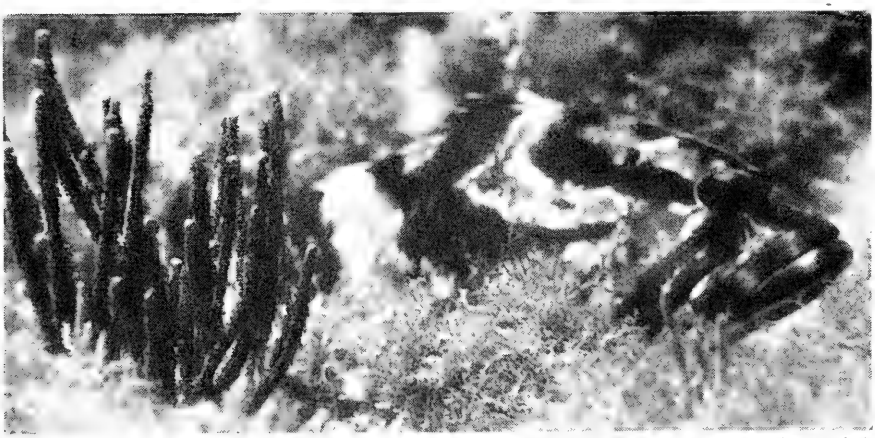
fishes. Such a structure is known to the ichthyologist as a "finlet". Finlets occur chiefly among the mackerels and tunas and their relatives. These fins are placed behind the second dorsal and anal fin and vary in number from 1 to 10, according to the species.

In the vast majority of spiny-rayed fishes the ventral fins are attached to the



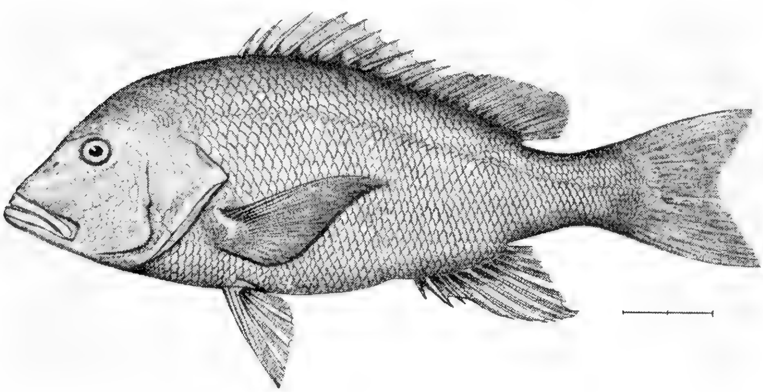
(Courtesy U. S. Fish and Wildlife Service)

Fig. 10–9. Red grouper (*Epinephelus morio*).



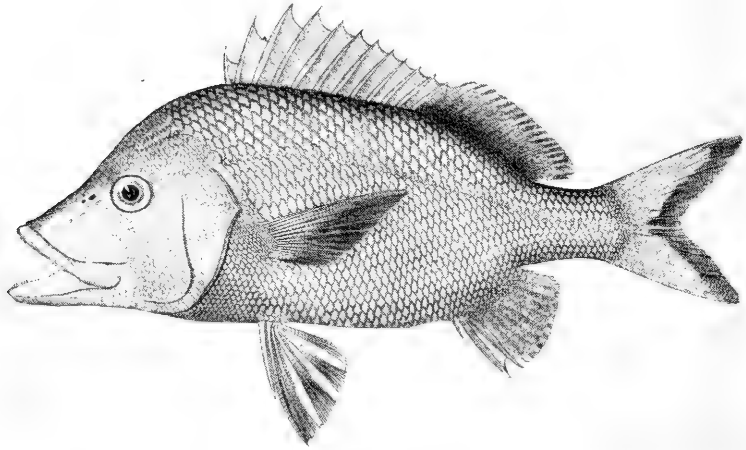
(Courtesy U. S. Fish and Wildlife Service)

Fig. 10–10. Nassau grouper (*Epinephelus striatus*). Family: *Serranidae* (sea bass); note protective coloration.



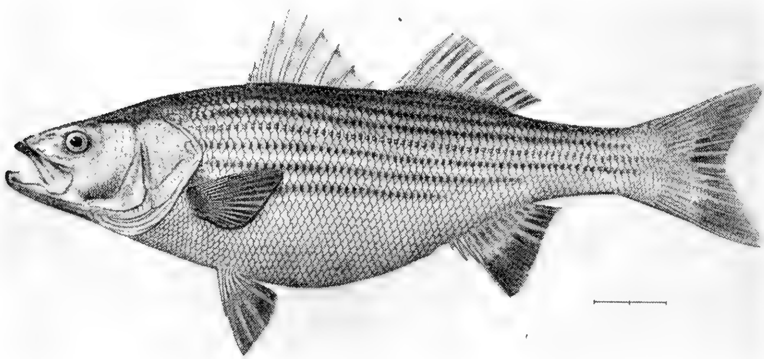
(Courtesy U. S. Fish and Wildlife Service)

Fig. 10–11. Florida red snapper (*Lutianus blackfordii*).



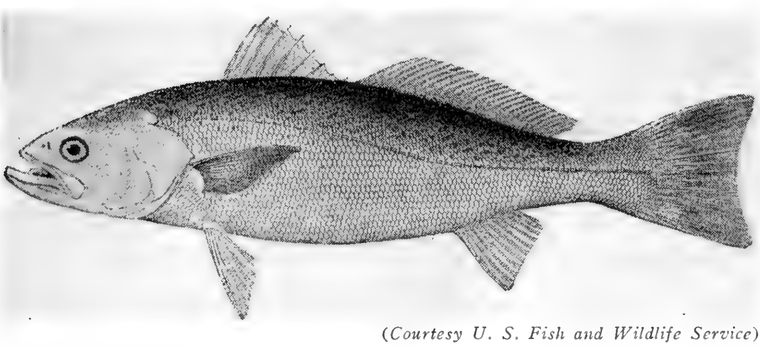
(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–12. Common grunt (*Haemulon plumieri*).



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–13. Striped bass or rock fish (*Roccus saxatilis*).



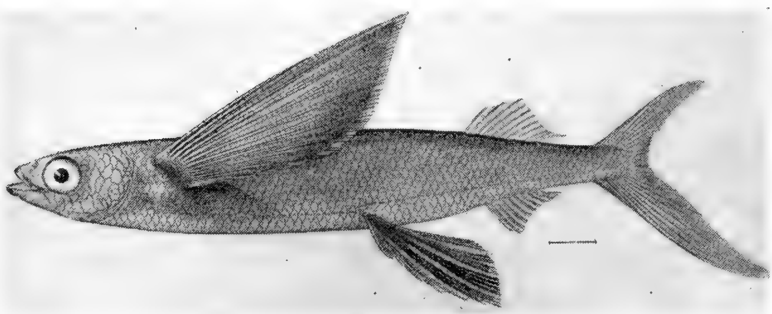
(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–14. Common squeteague or weakfish (*Cynoscion regalis*).

thorax often more or less under the bases of the pectoral fins. Fins occupying such a position are said to be "thoracic". However, in some spiny-rayed fishes the ventral fins are attached well in front of the pectoral fins, that is under the head. When they are so situated they are said to be "jugular". The blennies, toadfish, stargazers, and several other groups belong to the jugular fishes. The ventral fin in spiny-rayed fishes is usually composed of one spine and a few to several soft rays, the most usual combination among our common food fishes being one spine and five soft rays. The number sometimes is reduced, however, to 1 spine and 1, 2, or 3 soft rays, as in the sticklebacks, blennies, and others.

Regeneration of Fins. If the "limbs" or fins of fish are broken or bitten off, they will generally regrow. The regenerated fins may be somewhat deformed, and so can be distinguished from the normal ones. A remarkable case of regeneration in a pipefish, *Doryichthys lineatus*, was observed by the writer. This particular fish had apparently lost part of its tail in addition to its caudal fin as it had fewer caudal rings than normal. Yet, a somewhat dwarfed and twisted regrown fin was present on the last caudal ring.

Function of Fins. The powerful muscles in the tail of the fish cause the caudal fin to be used as a paddle for propulsion. The other fins serve chiefly as balancing organs. A remarkable departure from the usual function of the paired fins occurs in the flying fishes; the pectoral fins and in some species both the pectoral and ventral fins are used as organs of flight. However, the fins do not function as



(Courtesy U. S. Fish and Wildlife Service)

FIG. 10–15. The California flying fish (*Exocoetus californiensis*).

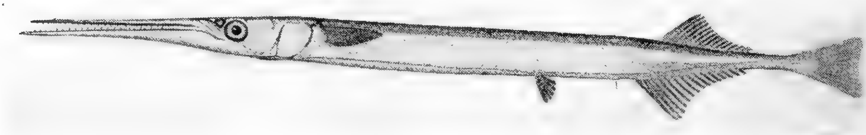
organs of propulsion like the wings of a bird; rather, they are used only for soaring or gliding. In effect, the fish takes a powerful leap from the water, and when once in the air the large fins spread widely, helping the fish to glide distances of 100 feet or more (Fig. 10–15).

The Mouth. The shape, size, and position of the mouth vary greatly. The most usual type is that possessed by the common Atlantic herring, *Clupea harengus,* in which it is of moderate size, slightly oblique, and nearly terminal. Varying from slightly superior to slightly inferior, it occurs among many common food fishes, as, for example, codfish, sea bass, mullets, mackerel, snappers, and many others.

A wide departure from the usual type of mouth occurs in the barracudas, which have very strong, greatly prolonged jaws and a large mouth, similar to the

fresh-water gars. The salt-water gars, too, have greatly produced jaws (Fig. 10–16), but they are weak. The halfbeaks, as the name implies, have only one jaw, the lower one, greatly produced. This is an instance of a superior mouth which is nevertheless nearly horizontal. Swordfish, marlins, and sailfish, on the other hand, have a produced upper jaw and, therefore, an inferior mouth, which is, as in the halfbeaks, nearly horizontal (Fig. 10–17).

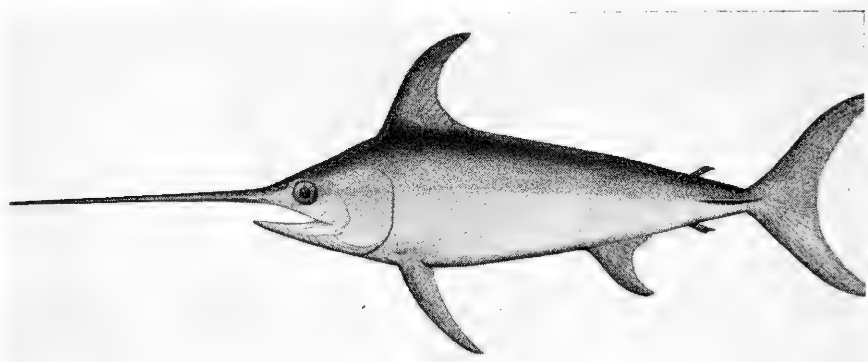
Inferior mouths, though less common than terminal mouths, may be found among the numerous species of sharks, skates and rays (Fig. 10–18), and



(Courtesy U. S. Fish and Wildlife Service)

Fig. 10–16. Needlefish (*Tylosurus marinus*) or salt water garfish.

sturgeons (Fig. 10–19). Superior mouths are not uncommon either, though perhaps less common than the inferior. They occur among the anglers, which have excessively large mouths in proportion to their size. In fact, the common angler, *Lophius piscatorius,* of the Atlantic Coast of the United States, is commonly known as "allmouth" because of its excessively large oral opening. Superior mouths occur even among the large family of croakers, sea trout, and drumfish (*Sciaenidae*), as in the genera, *Larimus* and *Nebris,* and also in stargazers, frogfish, etc.

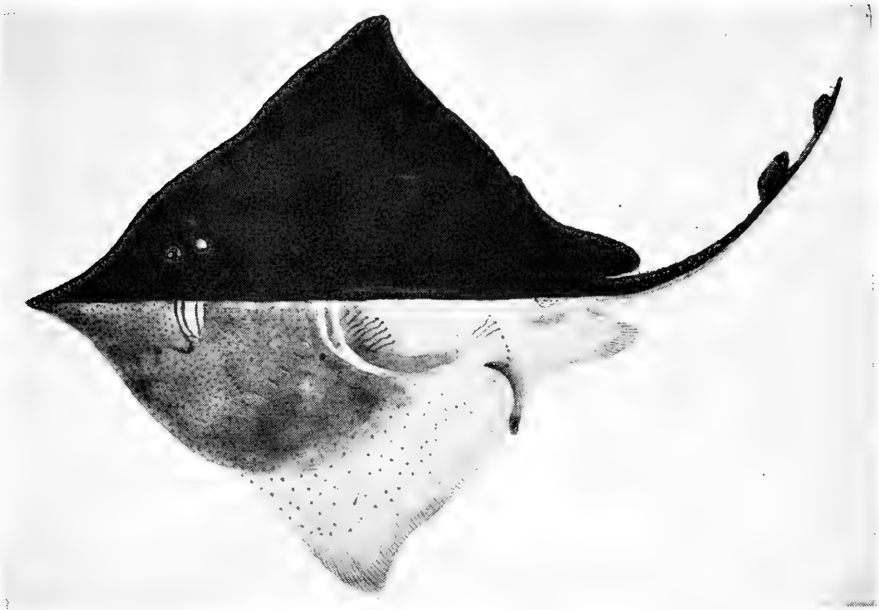


(Courtesy U. S. Fish and Wildlife Service)

Fig. 10–17. Swordfish (*Xiphias gladius*).

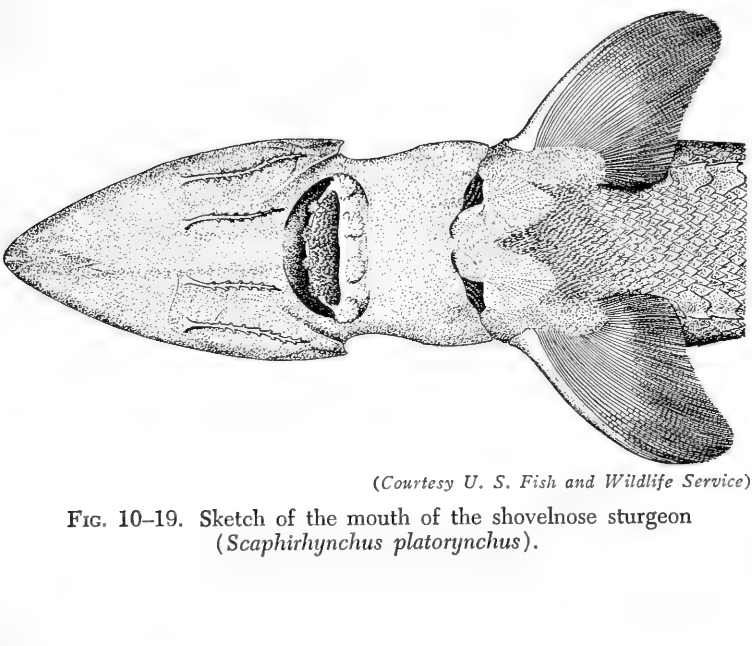
It is interesting that in many species the position of the mouth changes during growth. Commonly, it is vertical, or at least strongly oblique, in the larvae and becomes terminal or even somewhat inferior in the adult. Such a change occurs in the Spanish mackerel, *Scomberomorus maculatus,* spot, *Leiostomus xanthurus,* croaker, *Micropogon undulatus,* hake, *Urophycis chuss,* etc.

Teeth. Teeth, like the other structures of the fish, differ greatly among the various groups, or even within a family. While virtually all young fish, that is postlarvae and young adults, have teeth, they are sometimes lost later in life. The



(Courtesy U. S. Fish and Wildlife Service)

FIG. 10–18. Barndoor skate (*Raja laevis*).



(Courtesy U. S. Fish and Wildlife Service)

FIG. 10–19. Sketch of the mouth of the shovelnose sturgeon (*Scaphirhynchus platorynchus*).

common Atlantic herring, *Clupea harengus,* already referred to several times in these pages as a common type of fish, has teeth in its jaws when young, but loses them or retains only minute ones when full grown. A related herring, the common shad, *Alosa sapidissima,* entirely loses its teeth as it attains the adult stage. However, the jaw teeth in the herring family, *Clupeidae,* are not always lost with age. Indeed, in the small tropical species, *Chirocentrodon bleekeriana,* the teeth become larger and even fanglike.

In some fishes, such as spadefish, mullets, and others, small or weak cardiform teeth persist. At the other extreme are the triggerfish which have large incisor-like teeth. A specimen of the triggerfish, *Balistes naufragium,* 22 inches long, taken near Balboa, Canal Zone, has incisors not unlike those of a grown man in size and shape. Through a painful experience the writer learned that a triggerfish can use its teeth very effectively for cutting. Barracudas, bluefish, etc., have large compressed pointed teeth, whereas the cutlass fish have large, somewhat curved and compressed teeth. The parrot fish have still another type, a sort of beak composed of small teeth fused to form a continuous cutting edge.

Sharks, skates and rays, and chimaeras, that is, the cartilaginous fishes, in general have teeth that differ from those of the bony fishes. As a rule they are more formidable, though variable in size. Unlike those of the bony fishes they are set in the gums instead of in the bone. The teeth of sharks commonly have a broad flat triangular cusp, often flanked at the base by one or more small cusps, the cutting edges of which are usually serrated. These teeth occur in several series. When the anterior or functional series wear out, the teeth are shed and replaced by the next row. This is true of the teeth in the man-eater, *Carcharodon carcharias,* and the tiger shark, *Galeocerdo arcticus,* both dangerous to man. However, all sharks do not have large teeth. In fact, the two largest species of living sharks, the giant whale shark, *Rhincodon typus,* and the huge basking shark, *Cetorhinus maximus,* have very small teeth and feed on nothing larger than perhaps a fish a few inches long.

The teeth in many skates and rays are very different from those of the sharks, as they often are flat and arranged like bricks in a pavement. Such teeth occur in the giant eagleray, *Aëtobatis narinari,* sea devils, *Manta,* sawfish, *Pristes,* and many other skates and rays. The chimaeras or elephant fish, too, have teeth with flat surfaces.

Many fishes, in addition to having teeth in the jaws, also have them on the bones of the roof of the mouth, that is, on the vomer, palatines, and pterygoids; some are even located on the tongue and hyoid bone. Once more using the Atlantic herring, *Clupea harengus,* as an example, we find teeth on its vomer, palatines, and tongue. Indeed, it is the only member of its family on the Atlantic Coast of the United States and Canada that has teeth on the vomer; by this character alone it may be identified within its range on the American Coast.

Some fish have teeth on the pharyngeal bones, which are situated far back in the mouth. The members of the very large family, *Cyprinidae,* of fresh-water fishes, including carps and hundreds of species of minnows of the shiner type, have such teeth. The pharyngeal teeth in minnows are generally more or less pointed and often hooked. However, those of the black drum, *Pogonias cromis,* constitute an outstanding example of highly specialized pharyngeal teeth; they are low and flat and form, together with the bones in which they are set, a dental

plate. Perhaps the oddest place for teeth, exclusive of the denticles in the skin of sharks (discussed in the section dealing with body coverings, page 152) is in the anterior part of the oesophagus. Well-developed hooked and sometimes barbed teeth occur in this position in butterfish, *Stromateidae*, represented on the Atlantic Coast of the United States by 2 common food fishes, the butterfish, *Poronotus triacanthus*, and harvest fish, *Peprilus alepidotus*.

Teeth in fishes have 3 major functions: namely, grasping and holding the prey; cutting and rasping; and crushing. A good example of teeth adapted for grasping and holding occurs in the salt-water gars (*Belonidae*) which feed chiefly on small fish. Their rather long sharp teeth, already described, are suited for grasping and holding the prey while manipulating it into position for swallowing. The barracuda, *Sphyraena barracuda*, bluefish, *Pomatomus saltatrix*, and cutlassfish, *Trichiurus lepturus*, have teeth suitable for both holding and cutting. Teeth adapted primarily for cutting are possessed by parrot fish and many sharks, and those for rasping are found in the spadefish. Finally, the pavement-like teeth of the black drum, as well as those of many skates, are used for crushing.

It is evident from the descriptions of the size, position, and shape of the mouth, together with the discussion concerning the different types of teeth, that these characteristics constitute a clue as to where the fish seek their food, what kind they require, and how they acquire it. Although fish with vertical mouths, like the stargazers, obviously would not feed on the bottom, those with inferior mouths, like the sturgeons and skates and rays, would do so. Those with terminal mouths, including the vast majority of fishes, probably feed at any depth. It is impossible, however, to lay down any hard and fast rules in these respects, because some species with inferior mouths, as, for example, the vast majority of sharks, feed at the surface as well as at almost any depth. Furthermore, contrary to the more or less general public opinion they do not have to turn on their backs to grasp their prey.

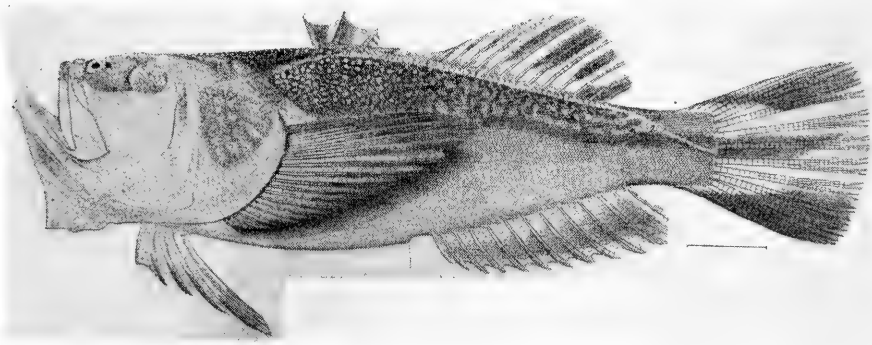
Teeth of the cutting type, possessed by many sharks, barracudas, bluefish, etc., break the prey into a size suitable for swallowing. Cardiform teeth, such as those of the spadefish and its relatives, rasp small plants, principally algae, from their anchorage. Broad flat teeth, with which many skates and rays, drumfish, and other species are equipped, crush mollusks and other hard-shelled animals. In many species the teeth seem to serve no other purpose than that of grasping the prey and holding it while it is worked into the proper position for swallowing, as stated in a preceding paragraph. Finally, it may be assumed that those fishes with minute teeth, or none at all, feed on small organisms which are usually screened from the water with numerous close-set gill rakers.

The Eye. The size and position of the eyes are quite as variable as some of the characteristics already discussed. It is possible to state definitely, however, that the eyes are never inferior in position (i.e., directed away from the light); they are either lateral or superior. In herrings, as in the vast majority of fishes, they are lateral; but in some species, as in the stargazers (Fig. 10–20), they are definitely superior (i.e., set in the top of the head). The remarkable change in the position of the eyes of flounders has already been related (p. 152). These fishes, which lie either on their left or right side, have the eyes on the upper side of the head. In other words their eyes, like those of the stargazers, look straight up.

In size the eyes vary from a mere dot, as in stargazers, to an inch or more in

diameter in small fish. For example, a specimen of catalufa, *Priacanthus arenatus*, 11 inches long, had eyes 1⅛ inches in diameter. Even proportionally larger eyes occur in some of the bizarre deep-sea fishes. Then there are quite a few groups of fishes that have no functional eyes at all, the best known among them the cave-dwelling blindfishes.

It is generally believed that sight in fishes, even those with large eyes, is poorly developed. As the lens is round most species are probably quite near-sighted. The author learned from experiments that the mosquito fish, *Gambusia affinis*, cannot see a wiggletail, or mosquito larvae, one of its principal foods, at a distance greater than approximately 3 inches and that it apparently cannot distinguish a bit of leaf stem or twig from a wiggletail at any distance within its



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 10–20. Naked star-gazer (*Astrocopus anoplus*). Family: *Uranoscopidae* (Stargazers).

range of vision. Furthermore, it seems to be able to detect motion more readily than the object itself. Thus, a wiggletail may escape notice when within the range of vision of the fish if it remains motionless. Moreover, it was learned that *Gambusia* does not feed in darkness and will do so during the night only when light is provided.

It is evident, then, that some fishes depend largely upon their eyesight to find food, whereas others, though blind, manage to live. Then, it is perhaps correct to say that eyesight is developed in fishes just to the extent needed in the environment in which they live and for the particular kind of food they require.

The Ear. Although fish have no external ear, they have an internal one, consisting chiefly of semicircular canals in which ear stones, or "otoliths," are found; these lie very close to the brain. It is certain that at least most fish can "hear," even though hearing may consist chiefly in detecting disturbances in the water. Hearing may be aided in some species by delicate sense organs within the *lateral line*, to which further reference will be made in a subsequent section.

The Nostrils. The vast majority of fishes have 2 pairs of pits variously situated in the snout, though usually lateral and in front of the eyes. Some species, however, have only a single nasal opening on each side of the snout. The nostrils in fishes, unlike those of the higher vertebrates, do not communicate with the throat. Through experimentation it has been proved that at least some fish can detect

odors in the water. However, this sense, as in hearing, may be assisted by the lateral line organs.

The Lateral Line. Most fishes have this plainly visible line, provided with pores, extending from the head or shoulder to the base of the caudal fin or even to the end of that fin. Tubes are connected with the pores in the lateral line, which contain numerous nerves, indicating that they are sense organs. Their function is not well understood. It is rather generally believed, however, that they are useful in detecting disturbances in the water. In detecting disturbances, sound waves, or odors in the water the lateral line organs may aid the fish in finding food and in avoiding enemies. Nevertheless, many fish, including herrings, shad, alewives, and mullets, have no lateral line and surely do not need one.

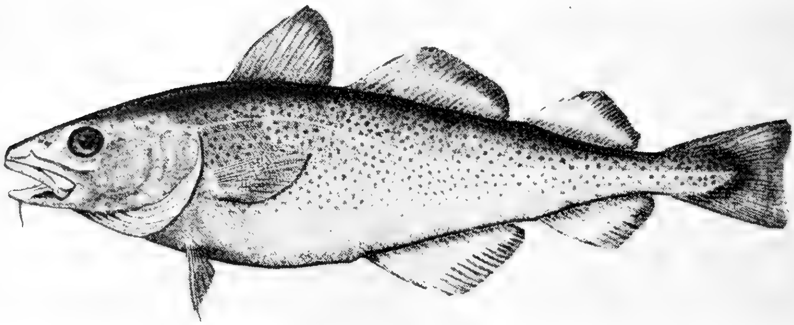
Tactile Organs. Special organs of touch, useful in exploring the bottom for food and perhaps also in avoiding enemies, are present in several groups of fishes. Tactile organs consist of barbels and generally of some sort of modified paired fins. Catfish, goatfish, codfish, croakers, etc. have barbels attached somewhere to the snout or lower jaw. Some other groups, such as blennies and scorpion fish, have barbels over the eyes or on the body, principally along the lateral line. Barbels may be long and slender, as in catfish and goatfish, or short, as in croakers and codfish. In some species they are single, as in the codfish (Fig. 10–21), few, as in goatfish and catfish (Fig. 10–22), or numerous, as in the croakers (Fig. 10–23).

The sea robins (*Triglidae*) and threadfins (*Polynemidae*) have feeler-like appendages attached to the pectoral fins, and the cusk eels (*Ophidiidae*) and some of the blennies (*Blenniidae*) have modified ventral fins that serve as tactile organs.

The Gills. Gills are to fish what lungs are to air-breathing vertebrates—organs of respiration. They are set behind the cavity of the mouth and consist of bony arches to the rear of which slender reddish filaments are attached. It is through these slender filaments that free oxygen in the water is absorbed and carbon dioxide is given off. On the anterior edge of the bony arches (generally known as gill arches or as branchial arches) is a series of projections, which may be few, short, and stubby at one extreme, or numerous, long, and slender at the other. In those species in which they are few and short, they serve no useful purpose; but in others that have numerous long close-set gill rakers, as, for example, the menhaden (*Brevoortia*) they are used in straining from the water small organisms upon which the fish feed.

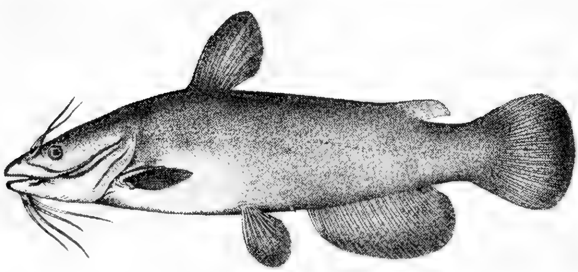
The number of branchial arches present varies somewhat among the different groups of fishes. The vast majority of bony fishes, however, have 4 pairs, with a single opening on each side of the head. Sharks and skates and rays, with few exceptions, have a separate opening, known as a "gill-slit," to each gill arch.

The Air Bladder. The air bladder or swim bladder is an elongated sac, with a thin semitransparent wall, lying close to the backbone in the abdominal cavity. It is in a measure comparable with the lungs of air-breathing vertebrates. Nevertheless, a "normal" air bladder seems to have nothing to do with respiration, its chief purpose presumably being that of providing buoyancy and helping the animal to rise and sink in the water. It is to be remembered, however, that many fish, such as the flatfish, sharks, and skates and rays, have no air bladder. Even such an active swimmer as the common mackerel, *Scomber scombrus,* has no



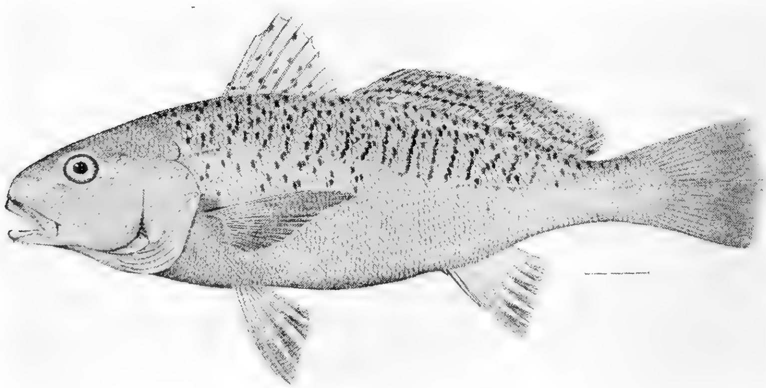
(Courtesy U. S. Fish and Wildlife Service)

FIG. 10–21. Codfish (*Gadus morhua*).



(Courtesy U. S. Fish and Wildlife Service)

FIG. 10–22. Small catfish, common bullhead or horned-pout (*Ameiurus nebulosus*).



(Courtesy U. S. Fish and Wildlife Service)

FIG. 10–23. Croaker (*Macropogon undulatus*).

swim bladder, except when very young, and it quite surely does not need one. It seems rather significant, however, that the species with primitive lungs, such as the lungfish, fresh-water gars, and tarpon, which do breathe air at least in part, have modified air bladders containing cellular tissue similar to that of the lungs of air-breathing vertebrates.

Air bladders in some species, as in the drums and croakers, are associated with "voice," the sound of which is little more than a drumming or croaking. This is especially well-developed in the croaker, *Micropogon undulatus*. It has been reported that during the recent war sonar operators heard a loud noise advancing steadily up Chesapeake Bay and suspected that it was enemy craft. Later it was learned that the noise was caused by a school of migrating croakers. Croaking or drumming is produced by muscles that "beat" on the inflated air bladder. Incidentally, it is from the walls of the air bladder that isinglass is manufactured.

The Alimentary Canal. The digestive tract in fishes may be long and coiled, or short and nearly straight. In some species its total length scarcely exceeds the length of the body, while in others it is several times the length of the fish. In general a short simple alimentary canal is associated with fish that feed on an animal diet, and a long complex canal with those that feed on plants. The mud-eating species, such as mullets, *Mugil,* and gizzard shad, *Dorosoma,* have stomachs with very heavy muscular walls, resembling the gizzard of a fowl. Most of the cartilaginous fishes have "leaves" in the intestine, forming a structure known as a "spiral valve." Many fishes have blind sacs, called "caeca," attached near the pyloric end of the stomach. These appendices may be few or many, rather long or short. The functions of the different structures of the alimentary canal are not fully understood and cannot be discussed in this brief account further than to remark that each fish is provided with the particular type of digestive system needed for the kind of food it eats.

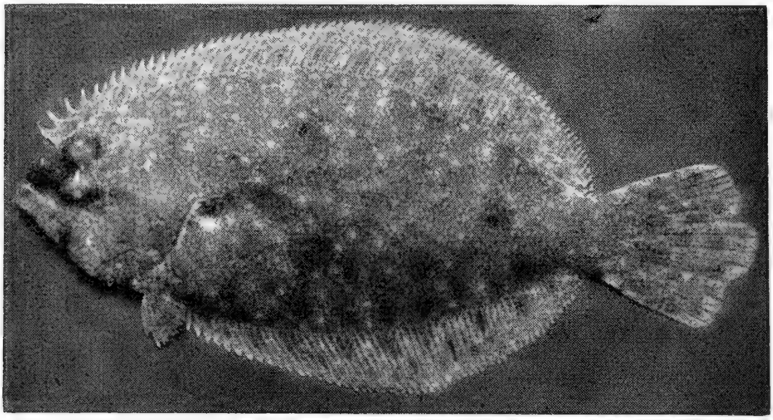
Color

The color of fishes is so variable among species and so changeable within species, or even in the individual fish, that the subject becomes intricate and can be treated only in a very general way. Some species are very somber in color and vary little with age, season, or environment. Others are brilliantly colored and changeable with age, season, and environment. The mosquito fish, *Gambusia affinis*, is an example of a very modestly colored fish, which at birth already has essentially the color of its parents, being plain greenish or olive above and pale underneath. It is comparatively unaffected by environment, though examples living among green vegetation or on a dark background are somewhat darker than those from a light bottom. The mosquito fish, unlike many other fresh and brackish water species, does not acquire bright hues during the breeding season.

The most brilliantly colored fishes, as a rule, occur on tropical coral reefs. Some of the reef fishes, as, for example, the angelfish, butterflyfish, and labroid and parrotfish, rival butterflies and moths in the display of bright colors and in their many hued patterns. Many fish undoubtedly bear protective colors, that is, colors that blend with the background and accordingly make them inconspicuous. It is difficult to imagine that the bright colors of the coral-reef fishes could serve such a purpose, yet those who have made observations under water have stated that

the brilliant colors blend fairly well with the coral heads, sea fans, gorgoneans, and other growths.

Convincing examples of protective coloration occur among flounders. Extensive observations and laboratory tests with species of the genus *Paralichthys* were carried on over a period of years at the Fish and Wildlife Service Laboratory at Beaufort, N. C. It was found that these flounders not only assumed the color of the bottom on which they lived, but imitated the pattern of the background. If



(Courtesy U. S. Fish and Wildlife Service)

FIG. 10–24. A southern flounder. Photo taken with orthonon plates of specimen adapted to colored backgrounds. Brown background. Note the remarkable simulation of the background in shade and the absence of conspicuous patterns, especially in *Paralichthys.*

placed on blue glass, for example, they took on a definite bluish tinge; if placed on red glass, they became red, and so on. If placed in a white enameled pan with large black spots painted on the bottom, the fish tended to "develop" large dark blotches over the black spots; but if placed in white pans with small black spots, they acquired the small dark spots: Or, if placed on coarse sand and broken shells, they took on a pattern of rather large dark and pale markings, but on fine sand the markings became mere specks. Wild fish were observed many times in nature, especially at night with the use of a strong flashlight. After some experience one learns to look for the outline of a flounder, rather than for the fish itself, as it has so accurately simulated the color and pattern of the bottom on which it lies that it is virtually invisible. There can be little doubt, then, that color affords protection. However, it may serve, also, in an offensive way, for a fish so well "hidden" would scarcely be detected in time by unsuspecting prey (Fig. 10–24).

The sexes in some species differ in color, the male being the brighter. These differences are sometimes so great that scientists were misled and described the sexes of one species as separate and distinct "species." Furthermore, the colors often change greatly with age. Indeed, fish hatched from eggs, unlike those born alive, are generally colorless. As a rule they develop color very gradually. The first pigment usually consists of a few dark chromatophores, and in many species the young do not become fully pigmented until they are a couple of inches long.

Even then they may not have the color pattern of adults. In general young fish tend to have the color pattern of females and do not become differentiated in this respect until about the time of sexual maturity. Even then the old males are usually more brilliantly colored than the young ones. Striking examples of confusion in classifying the brilliantly colored labroid and parrot fish have occurred because of pronounced differences in the color among individuals, between the sexes of one species, and between the young and adults. Males have been described as specifically distinct from their females and young distinct from their parents; even individuals of one species vary so prominently in color that they have been considered distinct species.

Nuptial or breeding colors are common among fresh-water fishes, but rather rare among marine forms. In general males respond to a greater extent in this respect than females. Commonly, the fins of fresh-water fish become yellowish or red when the animals are in spawning condition. Frequently, these bright colors spread over at least the ventral section of the body in the males.

It is not yet possible to explain the utility, if indeed there is any, of the colors and patterns of fishes, as already indicated in regard to the brightly colored tropical-reef fishes. As pointed out above color in some fishes provides protection, and it has been thought that sexes at breeding time recognize each other by certain special markings. However, to the taxonomist the red, blue, green, yellow, and black spots, bars, ocelli, and other color markings serve as recognition marks in determining species.

Foods

The type of food consumed by any species of fish is dependent on the structure of its mouth, teeth, gill rakers, and digestive tract. As these organs differ widely in structure, it follows that the foods upon which fish feed also vary widely. There are indeed few aquatic animals of suitable size upon which fish do not feed, and some terrestrial ones, such as insects and birds, are included.

Some species are quite restricted as to food; others are virtually omnivorous. The black drum, *Pogonias cromis,* to which reference was made in the section dealing with teeth, feeds on the bottom and subsists almost entirely upon mollusks and some crustaceans, which it is able to crush with its broad, flat pharyngeal teeth. Spadefish (*Chaetodipterus*), on the other hand, feed mainly on small plants, especially algae, which they are able to rasp from submerged objects with their cardiform teeth. Codfish, *Gadus morhua,* are omnivorous, and fish of many different species, including their own, have been found in their stomachs. They also feed on shrimp and other crustaceans, both the surface and bottom-dwelling forms. Even a wild duck is occasionally captured. Also found in their stomachs are stones, probably taken incidentally with the hydroids, sea anemones, or other growth attached to them. However, such indigestible objects as pieces of wood and rope, fragments of clothing and old boots, a tobacco tin, and jewelry have also been removed. It is highly probable that cod, like many other fish, snap up and swallow any moving animals or objects in the water. The failure to distinguish between live edible animals and indigestible objects is due to their inability to see them clearly even at a distance of perhaps 2 or 3 inches, or less.

The size a fish attains offers no reliable criterion as to the size and kind of food it eats. Thus, the whale shark, the largest living fish, feeds on minute organisms,

including nothing larger than fish a couple of inches long. On the other hand the deep-sea swallowers are known to ingest fish exceeding their own length. The writer once took a tropical fresh-water goby, the gauvina, *Eleotris pictus,* 14½ inches long, which had swallowed another goby, *Gobiomorus maculatus,* 8½ inches in length. The head of this morsel was at the vent of the swallower and partly digested, while its tail was visible in the mouth of the larger fish. There are cases on record of fish that died in the effort of swallowing fish too large for them. The writer once had in his possession a large-mouth black bass, *Micropterus salmoides,* which evidently had choked in the endeavor to swallow another bass of its own kind, which was not much smaller than itself. In this case the tail of the smaller fish projected 3 or 4 inches from the mouth of the larger one. The Smithsonian Institution has on exhibit a 12-foot fossil skeleton of an extinct fish, *Portheus,* which died millions of years ago. Inside it is the fossil skeleton of a 6-foot specimen of the same species. It seems probable that the larger fish died because of its gluttonous cannibalism.

It has been shown that some fish feed on other fish and some on lower animals. The question as to what the lower animals feed on logically comes to mind. It may be said at once that, although animals may prey upon one another, the original source of their food consists of plants. In other words, "All flesh is grass," and at the bottom of the pyramid of fish food are plants. The most important are the single-celled microscopic plants, especially the diatoms. This is true because nearly all marine fish during their larval stages feed on minute plants. Indeed, some highly important commercial species, as the common herrings, *Clupea,* the menhaden, *Brevoortia,* and quite a number of others, feed on such organisms throughout life, while the vast majority change to a diet consisting of larger animals and plants. Similarly, the mollusks, crustaceans, and other forms of animal life that enter into the diet of fishes feed on single-celled plants in the larval stages. As in fishes, some forms never change from that kind of diet, while others eat larger organisms during their adult life.

This interlocking and intimate relationship of food among the various groups of aquatic animals has frequently been overlooked, or at least insufficiently considered, for the welfare of our aquatic resources. Too often, organic pollutions and chemicals discharged into ponds, lakes, streams, and arms of the ocean have been considered harmless unless fish were killed outright. Such a line of thought obviously offers false security, for it is evident from what has been said already that if one "link" breaks in the "chain" of food supply the fish population in that vicinity is doomed. It is entirely possible, of course, that the adults can withstand the pollution and obtain ample food for a time, but their young, and the young of the creatures upon which the adult fish feed, may be deprived of the necessities of life. If that is the case, such a polluted locality will produce no fish. It is evident, then, that the effects of pollutions is a difficult and complex study, to which too little attention has been given.

Migrations

The long migrations from the sea to the headwaters of rivers, made by some of the Pacific salmon (*Oncorhynchus*) have long amazed everyone. Those individuals of the king salmon that ascend to the headwaters of the Yukon River, for example, make a journey of a couple of thousand miles, fighting their way up

stream through rapids and falls, wearing themselves out in the process. When they finally reach the spawning grounds, their fins are frayed and sometimes some of their scales are missing. In short they are so exhausted that they die soon after spawning. The Atlantic salmon, *Salmo salar,* also migrates to fresh water to spawn, but unlike the Pacific salmon, it does not ascend long streams and does not die after spawning. In fact the same individual may return several times. Shad, alewives, smelts, and a few others also migrate from the ocean to carry out their reproductive processes. It is evident that they enter fresh water solely for that purpose as they usually do not feed during the migration and return to the sea almost immediately after spawning.

Fish that come from the sea and enter fresh water to spawn are said to be anadromous. The young of most of the anadromous fishes remain in fresh water only during their first summer and then follow the course of their parents to the sea. However, most of the salmon remain longer.

The migrations of fresh-water eels, *Anguilla,* are scarcely less wonderful than those of the Pacific salmon. However, these eels reverse the migration, for they leave the fresh water and "run" out to the deep sea to spawn. The chief spawning ground of the American eel is a region to the southwest of Bermuda, while that of the European eel may be a little further east and south, though probably overlapping. It is believed that fresh-water eels, like the Pacific salmon, spawn only once and die when the act is completed.

Fish that migrate from fresh water to the sea to spawn are said to be catadromous. The young eels, which are flat and more or less ribbon-shaped, are known as leptocephalus. They do not seem to tarry long in the spawning grounds, but soon undertake the migration to their home in fresh water. As the young of the American eel have only about a thousand miles to travel, they make the journey in about a year. However, since those of the European eel have to travel about three times as far, they require nearly 3 years. It is interesting that both the American and European eels remain in the leptocephalus or larval stage, regardless of age, until they reach the shallow shore waters, where they undergo the metamorphosis and then enter fresh water as young adults.

Although all fish do not make long journeys to carry out their reproductive processes, most of them do spawn in definite areas. For example, the so-called gray trout, *Cynoscion regalis,* is common in the harbor and estuaries of Beaufort, N. C., during the spring while the roe is developing. However, when nearly mature the large breeding fish disappear from inshore waters. At that time they "run" out to sea a short distance, deposit their eggs and milt, and in a few weeks' time some of them, at least, return to the inshore feeding grounds. Other species, such as the codfish, migrate to rather shallow water to spawn. In general fish migrate to those areas where favorable physical conditions for the young exist and where the food required by the larvae is normally present. Certainly, the critical stage in the life of a fish occurs when it has used up the yolk retained from the egg upon hatching and must begin feeding wherever it happens to be. If the minute organisms required by most marine fish are not immediately at hand, the larva of course perishes.

Migrations to the feeding ground are carried out more or less regularly. Such migrations are often closely associated with temperature. Thus, each autumn croakers or hardheads, *Micropogon undulatus,* leave Chesapeake Bay in great

numbers, only to return the following spring. It is not known definitely whether these migrations are induced by temperature or whether they are undertaken for the purpose of seeking better feeding grounds during cold weather. Fish are probably influenced by both. Northward and southward migrations to find a comfortable temperature and food also take place, but quite surely less extensively than was formerly supposed. There is some evidence which tends to show that more commonly fish merely migrate offshore to deeper water, rather than going on long northward or southward journeys.

It is not at all surprising, in view of the great extent of the watery home of marine fishes, that some of the powerful and rapid swimmers go on long journeys. It would not be surprising if some of the mackerels and mackerel-like fishes, such as tunas and swordfish, crossed oceans. In fact some slight evidence that bluefin tunas, *Thunnus thynnus,* cross the Atlantic was obtained some years ago by a European investigator.

Geographical Distribution

It is obviously much more difficult to determine the geographical range of fish than that of land animals, whose courses or trails can actually be traced. It is perhaps correct to say that the exact range of few marine fishes has been determined. Nevertheless, not many distribute themselves widely as it is not necessary for their well-being. Fish are generally prompted to rove by temperature, water pressure, the presence of the proper food, the presence of enemies, and other factors not yet well understood. Recent critical studies have shown that the individuals of one species usually do not roam from one extreme to the other of their range. For example, it has been found that there are several geographical races of the anchovy, *Anchoa mitchilli,* and that those from the opposite extremes of the range differ so widely that the taxonomist would be justified in classifying them as two distinct species if specimens from the intermediate localities were not available for comparison. However, with specimens from many intermediate localities at hand for study, it was possible to show that there is complete intergradation. Furthermore, it was shown that different sections within the range, as New England, the Middle Atlantic States, the South Atlantic States, the Gulf States, and Yucatan, all had distinctive races. This discovery seems to indicate that the individuals of this species of anchovy, at least, do not roam widely, even though they seemingly could do so if they had the urge.

It is chiefly among the pelagic fishes of the mackerel and mackerel-like groups, which are powerful swimmers, that the widely distributed species occur. However, several of the larger species of shark, bluefish, common mullet, etc. are reported from widely separated seas. Even the common Atlantic herring has a wide range as it occurs on both sides of the North Atlantic, ranging from northern Labrador to Cape Hatteras on the American side. Yet, this herring can scarcely be classed as a fast and powerful swimmer. A particularly poor swimmer of very wide distribution is the porcupinefish. There are widely distributed species, also, among the deep-sea fishes, such as the lantern fishes. It is quite probable that further studies will show that most of these widely distributed species are composed of geographical races or subspecies; there may even be more than one species under the same name. With some exceptions individuals of these various groups do not travel from sea to sea.

On the other hand many species of marine fish are of comparatively limited geographical distribution. For example, the sea bass, *Centropristes striatus* and the common weakfish, *Cynoscion regalis* range only from Cape Cod, Mass., to northern Florida; the white perch, *Morone americana,* from Nova Scotia to South Carolina; and the tautog, *Tautoga onitis,* from the Bay of Fundy to South Carolina. These are all common food fishes. Many others from the same general vicinity, as well as from other shores, could be named with a similarly restricted range. Furthermore, the species named, as well as many others, are confined to comparatively shallow water along the shore, which still further limits their range. Then there are also some more or less obscure species that are known from only a few specimens and from only one locality. For example, a species of menhaden, *Brevoortia brevicaudata,* although described in 1878, is still known only from the 8 specimens originally described from Noank, Conn.

Geographical distribution of fish has also been influenced in some areas by geographical changes, which in some instances have removed barriers and in others created new ones. An excellent example of the formation of a new barrier is the elevation of the Isthmus of Panama. Not long ago, as geologists reckon time, fish from the Atlantic and the Pacific oceans intermingled there freely. In the course of time this passageway became closed, separating the representatives of many species of fish. Since then some of the species have yielded slowly to changes in environment, some not at all. Others yielded more quickly. The result is that today a small number remain common to both coasts of Panama, whereas the majority are separable by small, though not trivial, differences in their anatomy.

Physical and biological disturbances, too, have affected the distribution of fish, at least temporarily. A case in point is that of the tilefish, *Lopholatilus chamaeleonticeps,* abundant off the coast from Massachusetts to New Jersey prior to 1882. In that year steamers arriving from Europe reported thousands of square miles of the ocean's surface covered with dead tilefish, and thereafter this fish disappeared from the markets. Some fish survived, however, and by about 1915 the species had reestablished itself in commercial abundance. This catastrophe, it was determined, was probably caused by Arctic ice that had been driven into the home of the tilefish by northern winds and had made the water too cold for their welfare.

Spawning and Reproduction

All fish, so far as known, have rather definite spawning seasons, as well as definite spawning grounds. The season varies according to species, though the vast majority spawn during the spring and early summer. However, more than a few common commercial species, such as the cod, several species of flounder, the common croaker, the menhaden, and others spawn during the fall and winter.

The spawning grounds, which are also the feeding grounds of the newly hatched fish, are extremely important. Conditions for the incubation of the eggs must exist; and, equally important, the area must provide the proper temperature and food needed to help the larval fish through the very critical stage when they begin acquiring their own food.

It was pointed out in a preceding section that some fish migrate to the shore and some ascend fresh-water streams to spawn. Others, such as the weakfish,

Cynoscion regalis, spot, *Leiostomus xanthurus,* and common croaker, *Micropogon undulatus,* tend to move offshore to spawn, though few seem to go to the deep sea. These are all provisions made by nature to insure the perpetuation of the species, for it may be pointed out again that each species requires special conditions for the incubation of the eggs and especially for the survival of the young.

The vast majority of fish have eggs, which are fertilized the moment they are laid. However, in certain forms, as in some of the skates and rays, the eggs are fertilized internally and laid afterwards. The "mermaid's purse," known to all who have spent some time on the seashore, is the case of the eggs of a skate. Still other fish give birth to live young. Many, though not all, sharks have live young, as do the so-called viviparous perches of the Pacific Coast and the viviparous top minnows of brackish and fresh waters. The principal difference between the viviparous and the oviparous species is that the eggs in the former are fertilized and incubated internally, instead of externally as in the latter. Some sharks do have a sort of placenta, but to what extent it functions in supplying nourishment to the young remains relatively unknown. Nevertheless, it is among these lower forms of fish that the nearest approach in the reproductive process to the mammals is found.

In general fish cast their eggs in the water on their customary spawning grounds, then provide no further care for them. However, there are exceptions. Pipefish and sea horses, for example, provide excellent care, for the female transfers the eggs to a pouch which the male has for the purpose. There the eggs are incubated, and later the males give "birth" to young. Most, if not all, of the rather numerous marine catfishes, also provide protection for their eggs. In these the female somehow transfers her eggs to the mouth of the male parent, where they are incubated and the young retained until the yolk is absorbed.

Fish eggs "come" large and small and of different shapes. The marine catfish which practice mouthbreeding, or "oral gestation," have relatively large eggs, those of the common gaff-topsail catfish, *Felichthys felis,* being approximately an inch in diameter. The cases of skate eggs, that is the "mermaid purses," are flat and may be 2 to 3 inches or so square. At the other extreme are the eggs of the fresh-water eels, which are said to be almost microscopic in size. Pelagic eggs are usually small, frequently only a millimeter or so in diameter. Generally fish eggs are spherical, but those of the anchovies are ovate. Demersal eggs, such as those of the silversides, are often provided with gelatinous strands by which they become attached to submerged objects.

Some fish have comparatively few eggs, whereas others produce them in tremendous numbers. The now well-known mosquito fish, *Gambusia,* which hatches its eggs internally, generally produces less than 100 at a time, though several batches mature during one summer. The gaff-topsail catfish, which has been referred to as among the mouthbreeders, has, for a fish, enormous eggs, an inch or so in diameter; however, the number produced by a single fish is small, ranging from about 24 to 55. Salmon, too, have relatively large eggs which are comparatively few in number. The king salmon, for example, is said to produce about 5,200 which are around 5 mm in diameter. According to one author as many as 40,000 eggs occur in a common Atlantic herring, 635,500 in a sturgeon, 3,500,000 in a halibut, and 9,344,000 in a cod. It has also been estimated that as many as

12,201,984 immature eggs were present in a tarpon 80 inches long. Those eggs produced in large numbers are quite small, generally only a millimeter (about one-twenty-fifth of an inch) or so in diameter. Nature seems to have made provision for a greater mortality among the young hatched from minute eggs, which are extremely weak and delicate in comparison with those born alive or hatched from large eggs. If every egg produced by those species, like the cod, for example, were to live and mature, it is not difficult to see that the ocean would become overpopulated.

Larval Development

The larvae and postlarvae of fishes all differ more or less from their parents. Young eels, as stated elsewhere, are flat, ribbon-shaped, and virtually transparent. While going through a sort of metamorphosis they become shorter and rounder. Most young fish do not have fins, but only "fin folds." They have relatively large heads and eyes and are virtually colorless. Even in the postlarval and young adult stages they are often quite different in shape and color from their parents. Frequently, large spines are present about the head, but they are lost during development. Also, marked changes in the position and shape of the mouth, teeth, gill rakers, and alimentary canal take place. Such differences seem to be associated with a change in diet, for it was shown in an earlier section that nearly all marine fish at first feed on small or microscopic organisms, even though many later become carnivorous and feed on comparatively large animals.

Effects of Fishing

Overfishing has in many cases caused the fish to be less abundant. In fact there has been such a great reduction in some areas as to make fishing unprofitable. The chances of exterminating a marine fish through overfishing are quite remote. Although several species of birds and mammals have become extinct during the past several centuries, the writer is unaware of any fish that has met a similar fate. It is evident, nevertheless, that more than a few species are decreasing gradually although it is not always wholly due to overfishing by any means. Too often man has polluted the shore waters and streams in which the anadromous species spawn. He also has built insurmountable barriers, in the form of dams, across such streams. The combined results of overfishing, pollution, and the construction of barriers have caused the Atlantic salmon to be no longer of commercial importance in the United States and the shad and alewives of far less value in many areas than formerly.

That some fishes can be restored, in a measure at least, to their former abundance through wise measures of conservation is evident from the partial restoration of the shad in the Hudson River. The elimination of pollutions, in part, and the regulation of the fishery have brought this fish back in commercial abundance. One of the most effective measures of conservation is the prohibition of fishing during the spawning season. The prohibition of fishing on a part of the feeding grounds for a period of years seems to be proving very effective in restoring the Pacific halibut to its former numbers. Unfortunately, the life histories of many of our commercially important fishes are still too imperfectly known to permit the application of effective measures of control.

The Geographical and Vertical Distribution of Some Commercially Important Fishes of the United States

The vast majority of common food fishes live near the shore or at least come near the shore at certain seasons. Many enter harbors, bays, inlets, and estuaries as soon as the weather is warm, and remain only until autumn. These shallow waters are sought because they are good feeding grounds during the warmer seasons. Other fish enter fresh-water streams to spawn, then die or return to the sea. Still others, rarely, if ever, approach the shore, but occupy offshore banks where the water is of a more uniform temperature throughout the year.

Some species live chiefly at the surface, and are said to be "pelagic"; others remain more or less constantly on the bottom, and are called "ground fish"; and still others dwell at various depths between the surface and the bottom. A strong correlation seems to exist between the usual abode of fish and the type of food they require. Fish, like many other animals, live to eat. Therefore, they may be expected to dwell where the richest pastures are, except perhaps as the urge to spawn causes them to go elsewhere for a period of time. Fish may also be expected to follow to some extent their food source. Thus, if schools of small fish, such as anchovies and small herring, are present, the fisherman expects to find bluefish. If small shrimp (*Mysis*) are present in abundance, the fisherman expects Spanish mackerel. In other words, the species named, and many others, migrate at least to some extent to find food. This explains, in a measure, why fish may be abundant in an area one year and scarce the next.

Among the common commercial species that more or less regularly dwell on the bottom of the Atlantic and Gulf coasts of the United States are flatfish and flounders. Of this group several species are present off the coast of every state from Maine to Texas, although no single species has such a wide range. The common croaker, which ranges from Massachusetts to Texas, is another of the ground fish. To this group belong the whitings, also known as king whiting, kingfish, sea mink, and sea mullet (*Menticirrhus*). Of this genus at least one species is present along the coast from Cape Cod to Texas. The red drum, also known as redfish and channel bass, with a range extending all the way from Massachusetts to Texas, may also be classed as dwelling chiefly on the bottom.

The pelagic fishes are represented by the common Atlantic herring, menhadens, mackerels, mackerel-like fishes, and several others. The Atlantic herring, which sometimes is considered the most valuable fish in the world, occurs on both coasts of the North Atlantic and ranges south to Cape Hatteras on the United States coast. The menhadens, which are represented by 2 species on the Atlantic and 2 on the Gulf Coast, range all the way from Nova Scotia to Texas, exclusive of southern Florida. The menhadens are perhaps the most abundant of our marine fishes. Although they are used sparingly as food, large quantities are reduced to oil, stock feed, and fertilizer. The mackerel are represented by several species, including the northern mackerel, *Scomber scombrus*, which occurs on both coasts of the North Atlantic and range from Labrador to Cape Hatteras, and the Spanish mackerel, cero, and king mackerel (*Scomberomorus*) which extends from Maine to Brazil. The tunas, prized chiefly as a sport fish on the Atlantic Coast, also belong to the mackerels. They are represented by at least 3 species, one or more being present from Newfoundland to the tropical seas. Swordfish, marlins, and

sailfish are often referred to as mackerel-like fishes. Likewise, one or more of these is present along the Atlantic Coast of the United States from Newfoundland to the tropics. Swordfish are of course a valuable food fish, but marlins and sailfish are sought only by sportsmen.

The mullets (*Mugil*) taken on the Atlantic Coast from Massachusetts to the tropics, can be classed both as surface and bottom dwellers. If they are not at the surface feeding on plankton, they are on the bottom stirring up ooze and feeding on the organic matter obtained.

A large number of important food fishes of the Atlantic Coast of the United States cannot be classed either as surface or bottom dwellers. Among them are the weakfish of the genus *Cynoscion* represented by one or more species from Cape Cod to Texas, by scups, pinfishes, porgies, and many other species.

Among the common commercial fishes that live chiefly at some distance offshore are codfish, haddock, pollock, several species of hake (*Urophycis*), halibut, and tilefish. All of these species are of northern distribution and are taken commercially only off the North Atlantic and New England states. The red snapper of the Gulf of Mexico also belongs to the group of commercially valuable fishes that lives in rather deep water offshore.

The commercially important anadromous fishes of the Atlantic Coast of the United States, though missing in the Gulf of Mexico, are the smelt, chiefly of New England, alewives (*Pomolobus*) and shad. The Atlantic salmon and Atlantic sturgeon formerly belonged to this group, but they have been so greatly reduced in number that they are no longer important. The striped bass or rockfish, *Roccus saxatiles,* and the white perch, *Morone americana,* both food fishes of importance along a large part of the Atlantic seaboard of the United States, are generally classed as anadromous species, though their journeys to fresh-water spawning grounds are not extensive.

The common food fishes of the Pacific Coast of the United States are, in large part, related to those of the Atlantic Coast. Indeed, a few are identical. Among them are several species of flounder; some are strictly shore fishes, while others occupy water of moderate depths. The Pacific halibut, like the Atlantic, with which it is considered identical, is one of those that dwells in rather deep water. It is a very valuable fish off the northwestern coast and ranges southward to northern California. The starry flounder, *Platichthys stellatus,* may be cited as a common shallow water shore form, ranging from Japan to Alaska and southward to Santa Barbara County, California. The flounders or flatfishes, some of which are marketed as "soles" on the Pacific Coast, dwell on the bottom, and are taken in relatively large quantities along the entire coast of the Pacific states. The rockfishes of the Pacific Coast, consisting of a number of species variously known as "black rockfish," "brown rockfish," "green rockfish," etc., which live principally among the rocks in shallow to moderately deep water, may also be grouped with the bottom dwellers.

Among the pelagic species of the Pacific Coast of the United States occurs the highly valuable sardine, *Sardinops caerulea,* taken along the entire length of the coast; the Pacific herring, which is closely related to the Atlantic herring, is taken in commercial abundance as far south as San Diego Bay; and the albacore, which is canned and marketed as "tuna," occurs in commercial numbers only on the coast of California. The bluefin and the yellowfin tunas, also, are among the

pelagic fishes of the Pacific Coast. These tunas are closely related to, if not identical with, species occurring in the Atlantic. The swordfish, believed to be identical with the Atlantic variety, also occurs off California. A few species of marlin, apparently different from those of the Atlantic, have also been reported from California. The "sierra" of the Pacific Coast, which is identical with the Spanish mackerel, *Scomberomorus maculatus,* of the Atlantic, and a related species *Scomberomorus concolor,* are other pelagic species occurring on the coast of California.

Species that are neither pelagic nor ground fish are represented by the barracuda, *Barracuda argenteus,* yellowtail, *Seriola dorsalis,* sea bass, *Cynoscion nobilis,* and of course many others. The species named are all commercially important. The first two occur on the coast of California and southward, and the last one ranges from Alaska to California, but is abundant chiefly on the coast of California.

Among the offshore species of the Pacific Coast, in addition to the halibut already mentioned, are the arrow-toothed halibut, *Atheresthes stomias,* taken from San Francisco northward, and another flatfish, namely the mottled sand dab, *Citharichthys sordidus,* which occurs along the entire coast of the Pacific states. To this group may be added the Pacific codfish, taken from Oregon northward, which is closely related to the Atlantic cod, and the lingcod, which occurs along the entire Pacific Coast.

The anadromous fishes of the Pacific, the last to be mentioned, are nevertheless highly important as they include the very valuable salmon. It is to be regretted, however, that the Pacific salmon on the coast of the United States are declining alarmingly, partly because of overfishing, but more particularly as a result of the construction of barriers in the streams they formerly ascended to spawn. To the list of commercially important anadromous fishes of the Pacific Coast two introduced species, namely the Atlantic shad and the striped bass, can now be added.

REFERENCES

Breder, C. M., Jr., "Field Book of Marine Fishes of the Atlantic Coast," New York and London, G. P. Putnam's Sons, 1948.

Carson, R. L., "Food from the Sea. Fish and Shellfish of New England," U. S. Fish and Wildlife Service, *Conservation Bull.,* 33 (1943).

Carson, R. L., "Fish and Shellfish of the South Atlantic and Gulf Coasts," Coordinator of Fisheries, *Conservation Bull.,* 37 (1944).

Carson, R. L., "Fish and Shellfish of the Middle Atlantic Coast," U. S. Fish and Wildlife Service, *Conservation Bull.,* 38 (1945).

Chapman, W. M., "Thrice Told Tales: 1. Concerning the Skin and Scales of Fish," *Aquar. J.,* **17,** No. 8 (1946).

Chapman, W. M., "Thrice Told Tales: 3. On the Respiration of Fish," *Aquar. J.,* **17,** No. 10 (1946).

Chapman, W. M., "Thrice Told Tales: The Ear of a Fish," *Aquar. J.,* **18,** No. 1, 8–17 (1947).

Chapman, W. M., "Thrice Told Tales. 6. What Is a Fish?," *Aquar. J.,* **18,** No. 2, 18–27 (1947).

Chapman, W. M., "Thrice Told Tales. 7. Long Distance Touch in Fishes," *Aquar. J.,* **18,** No. 3, 14–21, 29 (1947).

Chapman, W. M., "Thrice Told Tales. 8. How a Fish Swims," *Aquar. J.*, **18**, No. 4, 21–26; No. 5, 14–18 (1947).

Chapman, W. M., "Thrice Told Tales. 9. How the Fish Sees," *Aquar. J.*, **18**, No. 7, 22–27; No. 8, 18–22 (1947).

Chute, W. H., *et al.*, "A List of Common and Scientific Names of the Better-Known Fishes of the United States and Canada," *Am. Fisheries Soc., Spec. Pub.*, **1**, 45 (1948).

Clark, F. N., "The Life History of *Leuresthes tenuis*, an Atherine Fish with Tide Controlled Spawning Habits," Calif. Fish and Game Comm., *Fish. Bull.*, **10** (1925).

Clark, F. N., "Movements and Abundance of the Sardine as Measured by Tag Returns," Calif. Div. Fish and Game, *Fish. Bull.*, **61**, 7–42 (1945).

Clemens, W. A., and Wilby, G. V., "Fishes of the Pacific Coast of Canada," *Fisheries Research Board of Canada Bull.*, **68** (1946).

Curtis, B., "The Life Story of the Fish, His Morals and Manners," New York, Harcourt Brace and Co., 1949.

Graham, M., "The Fish Gate," London, Faber and Faber Ltd., 1943.

Hart, J. L., and Wailes, G. H., "The Food of the Pilchard, *Sardinops caerulea* (Girard), off the Coast of British Columbia," *Contr. Can. Biol. and Fish., N. S.*, **7**, 247–254 (1932).

Hildebrand, S. F., and Cable, L. E., "Reproduction and Development of Whitings or Kingfishes, Drums, Spots, Croakers, and Weakfishes or Sea Trouts, Family *Sciaenidae*, of the Atlantic Coast of the U. S.," U. S. Fish and Wildlife Service (Bureau of Fisheries), *Fish. Bull.*, **16** (1934).

Hile, R., "Structure and Senses of Fish," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **132** (1949).

Johansen, A. C., "On the Migrations of Herring," *J. du Cons.*, **2**, No. 1, 1–27 (1927).

Jones, J. W., and King, G. M., "Experimental Observations on the Spawning Behaviour of the Atlantic Salmon (*Salmo salar* Linn.), "*Proc. Zool. Soc. London*, **119**, Part 1 (1949).

Jordan, D. S., "Fossil Fishes of Southern California," *Stanford Univ. Publ., Univ. Ser.*, **38** (1919).

Jordan, D. S., "A Classification of Fishes, Including Families and Genera as Far as Known," *Stanford Univ. Publ., Univ. Ser., Biol. Sci.*, **3**, No. 2, 79–243 (1923).

Kyle, H. M., "The Classification and Phylogeny of the *Teleostei anteriores*," *Wiss. Meeres., Abt. Helgoland*, N. F., **14** (1923).

Kyle, H. M., "The Biology of Fishes," New York, The Macmillan Co., 1926.

Norman, J. R., "Fish Coloration," *Salmon and Trout Magazine*, **62**, 20–25 (1931).

Norman, J. R., "A History of Fishes," London, E. Benn Ltd., 1931.

Ogilvie, H. S., "A Preliminary Account of the Food of the Herring in the Northwestern North Sea," *Cons. Perm. Int. p. l'Expl. Mer, Rapp. et Proc. Verb.*, **89**, 85–92 (1934).

Rich, W. H., and Morton, F. G., "Salmon-Tagging Experiments in Alaska, 1927 and 1928," U. S. Bureau of Fisheries *Bull.*, **40** (1930).

Roedel, P. M., "Common Marine Fishes of California," Calif. Div. Fish and Game, *Fish. Bull.*, **68** (1948).

Russell, E. S., "The Overfishing Problem," Cambridge, England, The University Press, 1942.

Schultz, L. P., "Keys to the Fishes of Washington, Oregon and Closely Adjoining Regions," *Univ. of Wash. Publ. in Biol.*, **2**, No. 4, 103–228 (1936).

Schultz, L. P., "The Ways of Fishes," New York, D. Van Nostrand Co., 1948.

Schultz, L. P., and class, "The Breeding Activities of the Little Redfish, a Landlocked Form of the Sockeye Salmon," *J. Pan-Pacific Res. Institution*, **10**, No. 1, 67–77 (1935).

Silliman, R. P., "Fluctuations in the Diet of the Chinook and Silver Salmons (*Oncorhynchus tschawytscha*) and (*O. kisutch*) off Washington, as Related to the Troll Catch of Salmon," *Copeia*, **2**, 80–87 (1941).

Smith, O. R., "The Spawning Habits of Cutthroat and Eastern Brook Trouts," *J. Wildlife Management*, **5**, No. 4, 461–471 (1941).

Thompson, W. F., and Van Cleve, R., "Life History of the Pacific Halibut. (Distribution and Early Life History)," *Report of the International Fisheries Commission*, **9** (1936).

Wiborg, K. F., "Some Observations on the Food of Cod (*Gadus callarius* L.) of the O–II Group from Deep Water and the Littoral Zone in Northern Norway and from Deep Water at Spitzbergen," *Fisk. Skrift. Ser. Hav. (Bergen)*, **9**, No. 4 (1948).

CHAPTER 11

Fluctuations in Abundance of Marine Fishes: Their Measurement, Causes, and Prediction

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Introduction

Of all the characteristics of marine fisheries one of the most outstanding is the violent and usually unpredictable fluctuation of the catch. This aspect is of interest not only to the scientist and conservationist, but also to the practical fisherman because of its economic impact. Since some communities, as, for instance, certain towns in Norway, depend on successful fishing for their entire economy, extreme distress is experienced during periods of poor fishing. Therefore, attention has been focused on the fluctuations in marine fisheries almost from the beginning of the study of fishery biology. Interest in this subject was greatly intensified after the publication in 1914 of a paper, "Fluctuations in the Great Fisheries of Northern Europe," by the Norwegian marine scientist, Johan Hjort. Since that time the matter of fluctuations has continued to be of paramount importance to practically all marine fishery biologists, and a great deal of work has been done to ascertain the causes of the fluctuations and possible means of lessening their impact on the fishermen.

A very few illustrations of catch records from marine fisheries will serve to illustrate the type of fluctuations encountered. One of the most famous examples and the one which caused the economic upheavals in Norway was the Norwegian herring, the recent history of whose catch is shown in Fig. 11–1. Although the catch averaged about 700,000 metric tons from 1850 to 1870, it had fallen to 75,000 by 1904, as indicated in the graph. Low catch levels continued until 1925 when it surged up to about 600,000 metric tons, with fluctuations of greater or lesser degree since then.

Turning from the pelagic Norwegian herring to an anadromous fish we find the matter of fluctuations again exemplified in the catch of the Hudson River shad (Fig. 11–1). Here the earliest available data show the fishery already well developed. There was a catastrophic decline around 1904 followed by continued low catch levels for about 30 years. After 1935 very high levels were attained, until a peak of 5,000,000 pounds was reached in 1944. The years subsequent to 1944 seem to indicate the start of another decline.

Another anadromous fish of great commercial value is the Columbia River chinook salmon, the course of whose catch is depicted in Fig. 11–1. The story given here includes the early history of the fishery; it is somewhat similar to that of the

Norwegian herring and Hudson River shad, except that there were no periods of consistently low catches followed by catches even higher than formerly.

Returning to the marine pelagic species we find the matter of fluctuations

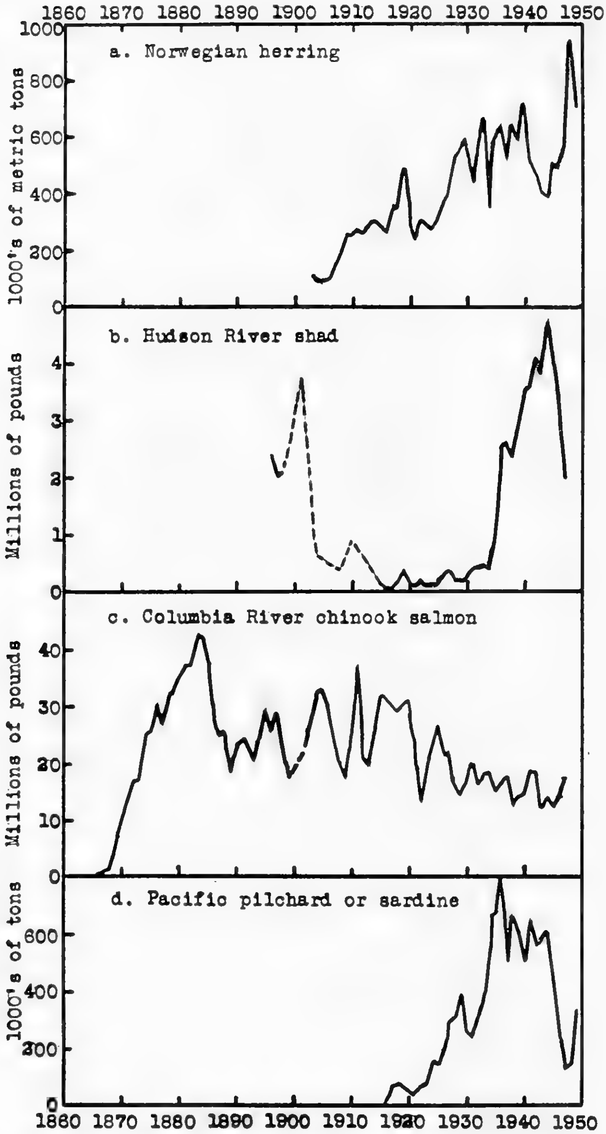

FIG. 11–1. Annual catches of some important fisheries (broken lines indicate missing data).

again very clearly illustrated in the catch of the Pacific pilchard or sardine (Fig. 11–1). This fishery was given its first great impetus by the demand for fish oil during World War I, and its significant history begins in 1916. Again there was a period of very great expansion, culminating in the high level of about 800,000 tons in the 1936–37 season. Then there followed some very moderate fluctuations

up until 1944–1948, when a drop to only 130,000 tons occurred in the 1947–48 season. Although the complete story will not be told until the catches of the next few decades are on record, it is already apparent from the increased catches in the 1948–1949 and 1949–1950 seasons that the fishery is beginning to recover. Before any intelligent study of the fluctuations in the abundance of marine fisheries can be initiated, it is necessary to find some method of measuring abundance. This procedure constitutes the subject of the next section.

Measurement

Selection of Method and Unit. In measuring the abundance of marine fish it must first be decided whether this abundance is to be expressed in terms of the number or the total weight of fish. Both methods have been used, with perhaps somewhat more emphasis on the former. It is also necessary to define the "stock" of fish. Very few fishery investigators consider this to be the total of all fish of a given species in an area studied at any given time. It is much more common and somewhat more practicable to measure the commercially available part of the stock, comprised normally of the larger and sexually mature members of the population. The division between "precommercial" or "juvenile" and commercial-sized fish is never sharply defined, and usually depends upon size at maturity and the amount of size selection exercised by the gear used. Thus, gill nets, for instance, are very selective in their fishing action, whereas seines and traps are much less so. Although illustrations of the fluctuations in the *catches* of marine fish have been given, it must be emphasized that the actual catch is very seldom a measure of the abundance of the fish.

The catch data, however, when used in connection with data on the amount of fishing effort expended (amount of gear and time of operation), provide a measure of catch per unit of effort, which is roughly indicative of abundance. This and other methods of estimating abundance will be discussed, but it is pertinent to note that in all cases the sampling problem is of particular importance. Except for the actual enumeration of the total population the estimate depends upon some type of sample, whether it is one of scales or lengths of fish, of catches from the stock or of fish eggs. In making estimates from these samples it is assumed that they are representative of the population as a whole, but unfortunately this assumption is often unwarranted. There are numerous opportunities for statistical error, and only by the greatest care and critical examination of the biostatistical methods used can gross inaccuracies be avoided. It is of the utmost importance to face the sampling problem during the planning stages of any investigation and to make sure that, while feasible with the facilities available, it is one which will give representative results.

Actual Counting. Simple enumeration is, of course, the most accurate method of determining the abundance of the stock at any particular time, but this method is applicable to very few marine fishes because of their inaccessibility. In fact the only ones that can be treated in this way are the anadromous species which migrate up streams and rivers during the spawning period. The method has been used particularly in connection with investigations of Pacific and Atlantic salmons. Fences or "weirs" are actually thrown across streams so as to completely block upstream migration. One or more gates, equipped with white boards over which the fish may be seen clearly as they pass through, are provided. Talliers, trained

in identifying the various species of salmon, are stationed above the counting boards and record the numbers of fish on mechanical counters. An outstanding example of this type of operation is at Bonneville Dam on the Columbia River.

At some places in Alaska and British Columbia the small downstream migrating salmon have also been counted by use of fine mesh weirs. At such installations the fish are either counted manually by dipping them a few at a time with a net from one part of a trap to another, or by measuring the volume of the fish and estimating the number from sample counts of known volumes of fish. Another method also used recently in salmon work is to enumerate the spawning adults by observations from airplanes. These are either direct visual counts or counts made from photographs taken while the plane is in flight over the spawning stream. The method is particularly valuable in open country, such as that found, for instance, in the spawning areas of the red salmon around Bristol Bay, Alaska.

A technique applicable only to the Pacific salmons (which all die after spawning) is the counting of the dead spawned-out fish. Obviously, this method is limited to shallow streams where the dead fish will not disappear from view.

Catch per Unit of Effort. This statistical measure, mentioned briefly above, is one of the oldest and most widely used methods employed for estimating the abundance of marine fish populations. Although the collection of the necessary records is often extremely complicated and difficult, the actual calculation is simple, consisting of merely dividing the recorded total catch by the estimated numbers of units of effort expended. The calculation may be made for an entire season or it may be done by weekly, monthly, or other convenient units. Various sources of error, such as differences among the boats and nets, changes in efficiency, and lack of comparable units from season to season, must be measured and adjusted. Assuming that the calculation has been accurately carried out, using data from a representative sample, it still does not always represent the estimate of the abundance of the fish, but only the availability of the fish to the fishermen. Obviously, if fish are not available to fishermen, they cannot enter into the calculated estimate of catch per unit.

Availability is affected by many things, including the size of mesh in the gear used, type of gear, places fished, and the natural variables which affect the migration or local concentration of the fish. Calculations of catch per unit of effort can often lead one far astray in attempting to estimate abundance if the factor of availability is present and has been overlooked.

Finally, even when the catch per unit calculation has been accurately made and the availability effect is lacking, or has been adjusted, the resulting index does not furnish a proper measure of abundance. This is due to the operation of certain rather complicated mathematical relationships which will not be described here. Suffice it to say, however, that in a good many instances catch per unit data require further treatment by mathematical methods if they are to represent the abundance of the fish.

Age Analysis. It is possible to determine the age of individual specimens of marine fish by counting certain rings on their scales, otoliths (small bones in the ear), fin rays, or other hard parts, techniques employed by fishery biologists for several decades. If these determinations are made on representative samples of stock, a distribution may be made of the fish of each age in the stock known as

"age distribution". From these age distributions it is possible to estimate the mortality rates by comparing the abundance of the successive ages of fish. These mortality rates in turn (when properly treated) can be used in conjunction with catch data to estimate the size of the stock from which the aged samples of fish were taken. In some instances it is possible to apply a similar method to size measurements of the fish where data on the growth rate are available.

Tagging or Marking. By means of identifying individual fish with some type of recognizable mark or attached tag it is possible to estimate the size of the total population. There is a very large number of types of tags in use, their variations depending upon the species of fish to which they are attached and the means by which the fish are handled after they are caught. The common strap cattle tag is used quite extensively on marine fish, being attached to the operculum or tail. Another type in common use (particularly on salmon where long life is unimportant) is the pin, consisting of two plastic disks which are placed on either side of the fish below the dorsal fin. A wire of noncorrosive metal is pushed through holes in these disks and also through the fleshy part of the back of the fish. The disks are usually printed with an identifying number, information regarding return of the tag to the marking agency, and the amount of reward which will be paid, if any.

For fish, such as herring, menhaden, and sardines, which are to be handled in reduction plants, metal belly tags are usually used. These are small pieces of metal about ¾ inch long and ¼ inch wide on which numbers are stamped. The tags are inserted into the body cavity of the fish through an incision which normally heals very rapidly. Recovery is made either by means of magnets placed under the dry meal lines of the reduction plants or by electronic detectors placed in the conveyors leading from the unloading hopper to the plant. These detectors cause a few fish to be diverted from the conveyor each time a tagged fish passes through. This method, although more expensive and difficult to operate, is advantageous in that it permits identification of the tag with a specific load of fish rather than with a full day or more of operation as is the case with the magnets.

Marking by mutilation of the fins is a widely used process, particularly with young downstream migrating salmon. In this method one or more fins are clipped off the young fish and instructions are given the cannery butchers as to the particular types of missing fin combinations to be expected on the adult fish and the means for returning the information to the marking agency and receiving the reward. The marking agency usually requires that the scars of the excised fins be returned to it in order that the reward may be claimed.

When data are at hand on the number of fish tagged or marked and the number recovered by the fishery, it is possible to estimate by simple proportion their total population. Thus, for instance, if 1,000 fish were marked and 500 recovered, it would be assumed that 50 per cent were taken and that the stock was, therefore, double the amount of the catch. In making such an estimation it is supposed that the tagged or marked fish are uniformly distributed throughout the population; however, this assumption must be carefully checked since it does not always hold true. Certain mathematical relationships also often disturb the simple direct proportion indicated above. In such cases adjustments, based on theoretical formulae, have to be made.

Egg Enumeration. If data are available as to the number of eggs laid each season by each female fish and the percentage of female fish in the population, it is possible, of course, to estimate the total population. The estimation of egg numbers itself constitutes a very important branch of fishery research and requires the use of extensive equipment and personnel. One or more boats are usually sent to sea to collect the floating eggs of pelagic species by means of fine meshed nets. These nets are towed at stations located on a regular pattern or grid covering the total spawning area. It is necessary to separate the eggs of the species to be studied from the rest of the plankton material collected in the nets and enumerate the eggs from each haul. By interpolation and integration, combined with a knowledge of the rate of incubation of the eggs, it is then possible to estimate the total number of eggs laid. With these data at hand a simple arithmetical calculation will transform the number of eggs into number of spawning fish.

Research Vessel Catches. For fisheries where extensive facilities for research are available it is sometimes possible to estimate the size of fish populations by means of the special catches of research vessels. These usually operate in a manner like commercial fishing vessels, but make their catches in a regular pattern instead of concentrating on the most heavily populated portions of the fishing grounds, as do the commercial fishermen. Catches of these research vessels are enumerated and the fish identified as to species, after which the data are treated in a manner similar to that indicated in the estimation of egg numbers.

Causes

The subject of causes of fluctuations has occupied the attention of fishery investigators and fishermen since the beginning of the world's great fisheries. It is easy to see why this is so, since a knowledge of the cause of fluctuations in abundance would either permit their control or their prediction, both of which items of knowledge would be of great value to the conservationists, fishermen, and fish processors alike. The known or suspected causes in the fluctuations in abundance of marine fish may be separated into two general categories, those of natural origin and those of man-made origin.

Natural Causes. Since marine fish spend all or almost all their lives in the open sea, it is natural to look into the changes in the hydrographic conditions of the oceans for the source of fluctuations in the numbers of fish present. It has been found by means of the age analysis just described that there is a tremendous variation in the size of the broods of many marine fish produced in different years. When this phenomenon was discovered it was natural to attempt to find some condition in the environment which corresponded to the success or failure of these year classes of fish. Many promising leads have been found and have proved reliable for a period of years, only to cause disappointment when there was a sudden deviation from the previously established correlation. Apparently, the relationships of marine fish to their environment are so complex that few, if any, of the studies to date have adequately accounted for all of them. Some of the ones which have been observed are of interest, and it is worthwhile to consider them.

As far back as 1908 the British investigator, E. J. Allen, discovered a rather close relation between the amount of bright sunlight recorded during February and March and the catches of mackerel. He theorized that sunlight causes in-

creased growth of plankton which in turn would provide increased food for the mackerel and attract them to the fishing grounds. This theory was sustained by the findings of another investigator whose data showed a close relation between the catches of mackerel and amounts of zooplankton (animal plankton as distinguished from plant plankton) observed in the same area.

In another well-documented study a considerable relation was shown between the catches of plaice and mackerel off the coast of Denmark and the local surface temperature of the water. In a study of the plaice fishery of the North Sea it was found that the percentage frequency of winds from certain directions was associated with the production of successful year classes of the fish. In this case the theory was that the proper winds would carry the young plaice from the spawning grounds to the good nursery areas where their chances for survival would be considerably enhanced. The temperature near the bottom was found to be related to the survival of cod fry in Scandinavian waters. When the bottom temperatures for 3-year periods occurring 4 years before the commercial catches (to account for the period of growth of the fish) were compared with the catches in question, it was found that there was a rather high correlation.

Populations of other species of fish in the same region also constitute part of the environment of a given marine fish, and the abundances are often interrelated. For instance, the Scandinavian cod feed rather heavily on the herring of the same region, and it was found that the catches of herring were inversely related to the catches of cod one year earlier. In other words it appeared that unusually high abundance of cod would cause excessive feeding on the herring population and a reduction of the latter.

Diseases and parasites have their effect on fish populations, just as they do on human, although great fluctuations from these causes appear to be rather rare. An example which has had considerable publicity recently concerns the decline of the catches of trout in Lake Huron. This occurred simultaneously with the appearance on the fish of extensive marks indicating attacks by the parasitic sea lamprey, which had entered the Great Lakes through the Welland Canal (built to permit navigation around Niagara Falls).

Long term or short term climatic changes affect the abundance of fish in particular areas in that they cause them to migrate to new regions. A recent example is the appearance off the Middle Atlantic Coast of considerable numbers of southern species not ordinarily found there. This was believed to be due to an unusually far northward extension of the warm waters of the Gulf Stream.

Man-Made Causes. First among the man-made causes affecting marine fisheries is undoubtedly the actual fishing itself. Conclusive proof has been found, for instance, that changes in the abundance of Atlantic haddock are associated with sizes of catches taken from the population. By means of the statistical analysis of catch and catch-per-unit-of-effort data alone, or in combination with tagging data, it is possible to estimate the actual percentage take of the fishery. In general it is found that a fishing rate which will keep the population not at its highest, nor at its minimum level, but rather at a middling level is the one which will result in the greatest continuing average yield.

In the case of anadromous fish anything which affects the streams in which the fish spawn will in turn affect the survival both of the upstream migrating adults and the downstream migrating young. Among these causes dams, irrigation diver-

sions, logging, and pollution are perhaps the chief offenders. In many cases it is possible to have these industrial and agricultural developments and at the same time preserve the runs of anadromous fish. This can be done by treating the polluting effluents, constructing fishways over dams, screening irrigation diversions, and applying modern scientific logging practices.

In exceptional instances the open sea itself may be affected by the activities of man. For instance, the farming of the "dust bowl" area might result in an exceptionally heavy load of silt in the Mississippi River, which, in turn, might provide more favorable shrimp growing grounds in the Gulf of Mexico. In recent years there has been extensive dumping of acid-iron wastes at sea in the vicinity of the mouth of the Hudson River. Many fishermen thought that this would have an adverse effect on fish, but extensive studies by oceanographers and fishery biologists have to date shown no basis for their fears. However, the dumping of oils from the bilges of ships may be harmful to the fisheries, particularly to such shellfish as clams and oysters which are close to shore. In most states the dumping of oil is prohibited in such areas.

Prediction

Prediction of fluctuations in the abundance of marine fish is of value, both to the fishery administrators and the fishing industry. By knowing the expected abundance of a given population in a given year, the fishery administrators can calculate how much gear should be allowed to fish, and for how long, to allow the appropriate percentage take determined from biological investigations. The fishermen and fish-processing industry may save considerable money by basing their operations on an accurate prediction of the amount of available raw material rather than on unreliable guessing. Because of the importance attached to this subject it has been studied extensively by fishery investigators in practically every major fish producing nation, and in some instances successful methods of prediction have been developed. The major methods will now be considered separately.

From Estimates of Fry Abundance. If it is possible in any way to estimate the abundance of young fish, it is, of course, possible to make some forecast of the anticipated catch of the adults resulting therefrom. The accurate estimation of the numbers of juveniles is difficult because of their habit of congregating in schools rather than being uniformly distributed over a large area. Even if accurate estimates of the abundance of fry are obtained, predictions may err greatly because of the variations in survival from the young fish stage to the first stage which enters the commercial fishery.

From Size or Age Composition. Analysis of the age composition of fish populations often shows a regularity in the relation between the abundance of a given age class in one year and the abundance of the next older age class in the next year. Where this is true, it is obviously possible to make a prediction for all but the youngest age involved in the fishery. For the latter it is necessary to depend on the fry estimates previously mentioned or on some average figure based on previous records. In some fisheries application of this method has led to predictions of considerable accuracy, although these occasionally go astray because of deviations from the regular pattern of progress of the age classes through the fishery.

From a Study of Cycles. In fisheries where the catch records have been kept for a long period (say 20 to 50 years) it is often possible to observe the occurrence of regular cycles of abundance. By application of certain methods of harmonic analysis it is possible to make extrapolations of these cycles much as is done by the Coast and Geodetic Survey in predicting tides. Because of short term deviations from these cycles predictions for individual years based on the cyclic treatment are usually not highly accurate.

From Mortality Rates. In fisheries where the recruitment of the young is very regular it may be possible to predict the yield of a fishery simply by a knowledge of the fishing mortality rate in effect as related to the fishing effort applied. An outstanding example of this is afforded by the halibut of the North Pacific area, where such a method yielded very close results for a considerable period of years.

REFERENCES

Allen, E. J., "Mackerel and Sunshine," *J. Mar. Biol. Assoc. United Kingdom,* n. s., **8,** 394–406 (1908).

Atkinson, C. E., "The Problem of Enumerating Spawning Populations of Sockeye Salmon," Int. Pac. Sal. Fish. Comm., *Ann. Rept., 1943,* 37–44 (1944).

Bullen, G. E., "Plankton Studies in Relation to the Western Mackerel Fishery," *J. Mar. Biol. Assoc. United Kingdom,* n. s., **8,** 269–302 (1908).

Chapman, D. G., "A Mathematical Study of Confidence Limits of Salmon Populations Calculated from Sample Tag Ratios," Int. Pac. Sal. Comm., *Bull.,* **2,** 69–85 (1948).

Clark, F. N., "Movements and Abundance of the Sardine as Measured by Tag Returns," Calif. Div. Fish and Game, *Fish. Bull.,* **61,** 7–42 (1945).

Craig, J. A., "An Analysis of the Catch Statistics of the Striped Bass (*Roccus lineatus*) Fishery of California," Calif. Div. Fish and Game, *Fish. Bull.,* 24 (1930).

Farran, G. P., "Fluctuations in the Abundance of the Various Year Classes of Food Fishes. XIV Fluctuations in the Stock of Herring on the North Coast of Donegal," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **65,** 124–128 (1930).

Graham, M., "Fluctuations in the Abundance of the Various Year Classes of Food Fishes. I Cod. Notes for the Discussion of the Fluctuations in Abundance of the Year-Classes of Cod (*Gadus callarius* L.) in European Waters," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **68,** 10–19 (1930).

Hjort, J., "Fluctuations in the Great Fisheries of Northern Europe," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.* **20,** 1–227 (1914).

Hjort, J., "Fluctuations in the Various Year-Classes of Food Fishes," I. Introductory Address. *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **65,** 5–9 (1930).

Howard, G. V., "A Study of the Tagging Method in the Enumeration of Sockeye Salmon Populations," Int. Pac. Sal. Fish. Comm., *Bull.,* **2,** 7–66 (1948).

Janssen, J. F., Jr., "Second Report of Sardine Tagging in California," *Calif. Fish and Game,* **24,** No. 4, 376–390 (1938).

Janssen, J. F., Jr., "Two Years of Sardine Tagging in California," *J. Cons. Perm. Int. Expl. Mer,* **14,** No. 1, 48–66 (1939).

Janssen, J. F., Jr., and Aplin, J. A., "The Effect of Internal Tags upon Sardines," Calif. Div. Fish and Game, *Fish. Bull.,* **61,** 43–62 (1945).

Jensen, A. J. C., "On the Influence of the Quantity of Spawning Herrings upon the Stock of the Following Years," *Cons. Perm. Int. Expl. Mer J. du Cons.,* **2,** No. 1, 44–59 (1927).

Jensen, A. J. C., "The Relation between the Size of the Plaice Stock and the Quantity of 'First-Class Plaice-Food' in Certain Parts of the Limfjord," *Dan. Biol. Sta. Rept.,* **34,** No. 5, 87–98 (1928).

Jensen, A. J. C., "On the Influence of the Size of the Stock of Cod upon the Yield of the Herring Fishery in the Kattegat, Belt Sea, and Western Part of the Baltic, and Some Other Causes of Variations in the Cod and Herring Fisheries," *Medd. Komm. Havund., Ser. Fiskeri,* **8,** No. 8 (1929).

Jensen, A. J. C., "On the Influence of Hydrographical Factors upon the Mackerel Fishery in the Sound," *Dan. Biol. Sta. Rept.,* **36,** 69–88 (1930).

Jensen, A. J. C., "Periodic Fluctuations in the Size of Various Stocks of Fish and Their Causes," *Medd. Komm. Havund., Ser Fiskeri,* **9,** No. 5 (1933).

Lea, E., "Fluctuations in the Abundance of the Various Year-Classes of Food Fishes. XII Mortality in the Tribe of Norwegian Herring," *Cons. Perm. Int. Expl. Mer Rapp. Proc. Verb.,* **65,** 35–44 (1930).

Lea, E., "Fluctuations in the Stock of Fish, Herring," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **65,** 35–44 (1930).

MacLulich, D. A., "Sunspots and Abundance of Animals," *J. Royal Astron. Soc. Canada,* **1936,** 233–246 (1936).

Ricker, W. E., "Relation of 'Catch per Unit of Effort' to Abundance and Rate of Exploitation," *J. Fisheries Research Board of Canada,* **5,** No. 1, 43–70 (1940).

Rounsefell, George A., "Methods of Estimating Total Runs and Escapements of Salmon," *Biometrics,* **5,** No. 2, 115 (1949).

Rounsefell, G. A., and Kask, J. L., "How to Mark Fish," *Trans. Am. Fisheries Soc.,* **73,** 320–363 (1943).

Schuck, H. A., "Relationships of Catch to Changes in Population Size of New England Haddock," *Biometrics,* **5,** No. 3, 213 (1949).

Silliman, R. P., and Clark, F. N., "Catch Per-Unit-of-Effort in California Waters of the Sardine (*Sardinops caerulea*) 1932–1942," Calif. Div. Fish and Game, *Fish. Bull.,* **62** (1945).

Sund, O., "The Renewal of a Fish Population Studied by Means of Measurement of Commercial Catches. Example: The Arcto-Norwegian Cod Stock," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **65,** 10–17 (1930).

Thompson, H., "Haddock Biology: (North Sea). A Brief Survey of Recent Data, Methods, and Results," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **54,** App. 2, 135–163 (1929).

Thompson, H., "Fluctuations in the Abundance of the Various Year Classes of Food Fishes. VI. Fluctuations in the North Sea Haddock Stock," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **65,** 35–44 (1930).

Thompson, H., "Fluctuations in the Various Year Classes of Food Fishes. II Haddock. On the Possibility of Effecting and Utilizing Accurate Estimates of Haddock Fluctuations," *Cons. Perm. Int. Expl. Mer Rapp. et Proc. Verb.,* **68,** 26–53 (1930).

Thompson, W. F., Dunlop, H. A., and Bell, F. H., "Biological Statistics of the Pacific Halibut Fishery (Changes in Yield of a Standardized Unit of Gear)," *Rept. Int. Fish. Comm.,* **6** (1931).

Thompson, W. F., and Bell, F. H., "Biological Statistics of the Pacific Halibut Fishery (Effect of Changes in Intensity upon Total Yield and Yield per Unit of Gear)," *Rept. Int. Fish. Comm.,* **8** (1934).

CHAPTER 12

Economic Importance of the World's Fisheries

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General

The fishery resources of the world are important, in varying degrees, to all nations. In most countries of the southern hemisphere the fisheries are of relatively negligible value and are often largely undeveloped. Their national fishery interests are frequently in only imported products suited to their diets. On the other hand the economics of such countries as Iceland, Newfoundland, and Norway are tied so intimately to their fisheries that a failure in the catch or a decrease in price adversely affects their whole economic structure.

Taken as a whole, however, the world's fisheries occupy an influential and, to some extent, unique place in the world's economy. The quantity and variety of the fish caught and the monetary value of the numerous processed products are substantial, but the ultimate worth and significance of these fisheries are also contributed to by other factors, equal in consequence, but more difficult to measure. These factors involve the many things the fisheries have supplied since civilization was young; they may even continue to provide them in increasing volume as the possibilities in fishery resources are explored.

The fisheries have always been a substantial source of the world's supply of protein. Fishery products are, however, not just another food. Nutritively, they rank high because they are readily digested, are obtainable as fat or lean products, and contain notable amounts of minerals and vitamins. They lend themselves readily for preserving processes, storage, shipment, and later use in areas distant from the sea. Canned fishery products enjoy a world-wide market, providing variety and economy to consumers of almost every nation. Dry-salted fishery products are staple foods in many warm countries because of storage problems, price, and the need for salt in the diet. Frozen fishery products led the way when freezing began to develop as a method of preservation. The importance of fishery products in connection with certain religious customs is well known. Less familiar is the increasing prominence of a so-called industrial nature: the fish meals and the fish oils which have become so valuable in animal-feeding programs, the vitamin-bearing oils which have contributed so much to individual and national well-being, and the pharmaceutical products now just reaching the market.

The fisheries provide a primary source of employment with many unique advantages. For example, it may be either practiced full time or combined on a part-time basis with some other occupation, such as farming. Similarly, the skills

and equipment required may vary from the simplest to a high degree of complexity in both the mechanisms employed and the training required. Family participation is not uncommon, and the minimum investment needed to begin operations can be nominal. The versatility available in fisheries extends also to the purpose for which the activity is pursued. Although they serve primarily as a source of lucrative employment, both those who engage in subsistence fishing to feed themselves and their families and those who fish for sport are appreciable in number. In more than one country, in time of need, fishermen have been available to form a solid core of skilled personnel on the rosters of naval and merchant vessels. Their fishing craft have also been invaluable as naval auxiliaries for everything from spotting the enemy to carrying supplies.

The role of the fisheries in exploration, migration, and trade has been impressive in the past and still prevails in the same tradition. The search for cod brought fleets to North America long before colonization occurred. Although modern vessels do not have huge unknown expanses to explore, they continue to seek new grounds in uncharted areas. Whalers would range the globe as formerly if conservation measures did not limit them to the Antarctic. Trade, migration, and settlement develop naturally after new fishing grounds have been discovered, simply because outlets for the catch can seldom be found locally and the urge to increase production usually demands a locally based operation.

Perhaps one of the most vital factors adding to the importance of the fisheries is the uniquely international character of the resource. The world's marine fishery resources are primarily international in nature. Of the United States catch, for example, an appreciable portion is taken off foreign coasts and a considerable part of the remainder is taken in international waters off the United States coasts. No other natural resource has the same status, nor is any comparable activity subject to similar international incidents and complications arising from jurisdictional disputes. Furthermore, fishery resources are renewable. They require no planting, only some means of harvesting the ever-recurring yield. This again complicates their status because of man's responsibility for only one part of the cycle.

Approaches toward solving the problems posed by the international character of fishery resources and their natural renewability have been made through international treaties, conventions, and proclamations. The most significant have been those which resulted in the establishment of such bodies as the International Council for the Exploration of the Sea in Europe and several treaties which have resulted in the management of the fur seal resources of the Pribilof Islands in the Bering Sea, the Pacific halibut fisheries, and the sockeye salmon fisheries of British Columbia and the State of Washington (Allen, 1936; Anon., 1939; Day, 1949). The proclamation issued by President Truman on September 28, 1945, entitled "Policy of the United States with Respect to Coastal Fisheries in Certain Areas of the High Seas," represents a new, but as yet unimplemented, development which, however, has brought forth similar but more far-reaching proclamations from a number of Latin American countries (Truman, 1945).

Bilateral and multilateral approaches include the convention between the United States and Mexico for the establishment of an International Commission for Scientific Investigation of Tuna and the convention between the United States and Costa Rica for the establishment of an Inter-American Tropical Tuna Commission (Anon., 1949d). The latter is multilateral, providing for the ad-

herence of other governments. The multilateral approach is also represented by the International Convention for the Northwest Atlantic Fisheries, which was developed in February, 1949, by representatives of Canada, Denmark, France, Iceland, Italy, Newfoundland, Norway, Portugal, Spain, the United Kingdom and the United States (Anon., 1949d). It has since been accepted by the United States Senate.

At the Geneva Conference of the Food and Agriculture Organization in 1947 it was recommended that FAO, through its Fisheries Division, "Take action to initiate the formation of regional councils for the scientific exploration of the sea in parts of the world not now actively served by similar bodies, giving primary consideration to the following areas: Northwestern Atlantic, Southwestern Pacific and Indian Ocean, Mediterranean Sea and contiguous waters, Northeastern Pacific, Southeastern Pacific, Western South Atlantic, Eastern South Atlantic, and Indian Ocean. The boundaries of these areas, and the constitution of the councils should be left open for discussion and determination by the nations concerned" (Anon., 1947). The first of these—the Indo-Pacific Fisheries Council—was established in March, 1949, with Burma, France, India, the Netherlands, the Republic of the Philippines, the United Kingdom, and the United States as members (Anderson, 1948). An agreement to establish a General Fisheries Council for the Mediterranean, developed at Rome in September, 1949, by countries interested in the area, has been approved by FAO (Anon., 1949b), and a Latin American Regional Council has been proposed.

Interest in the international aspects of the world's fisheries is increasing. But no simple and universally satisfactory solution to certain obvious problems, economic and otherwise, seems to be at hand. If the proposed multilateral discussions are unsuccessful, possession and exploitation of the world's fishery resources may become a much more serious matter, particularly since so much stress is being laid on the world's increasing population—55,000 new mouths to feed each day according to the Director-General of FAO. Some even doubt the ability of the land to produce after years of erosion and ill-advised farming practices. However, what the land has lost, the sea has gained. Though relatively unexplored, its fishery resources are probably on the threshold of their ultimate development and, therefore, are of economic importance far beyond the casual current conception.

Fishing Areas

The fishery resources of the world, as they have been developed or as we know them, are not equally distributed throughout the waters of the globe. In general it appears that abundance is linked to areas where the continental shelf is broad and the waters relatively shallow and productive of food. The temperate zones support tremendous populations of fish, consisting of relatively few species. The tropic zones have a great number of species, but no single species is comparable in volume to the cod, mackerel, herring, or salmon found in the colder zones. What the deeper ocean waters contain is a mystery, made only more fascinating by occasional research reports.

Sandberg reported on the status of the world's fisheries prior to the war and found that of the 37 billion pound catch, 98 per cent was taken in the northern hemisphere (Sandberg, 1945a). Forty-seven per cent of the catch was made in

the North Pacific Ocean, 46 per cent in the North Atlantic Ocean, 5 per cent in the Indian Ocean, and 1 per cent in the South Pacific and South Atlantic oceans. From a continental point of view Asiatics caught 49 per cent, Europeans 32 per cent, North Americans 16 per cent, and all others only 3 per cent (Fig. 12–1).

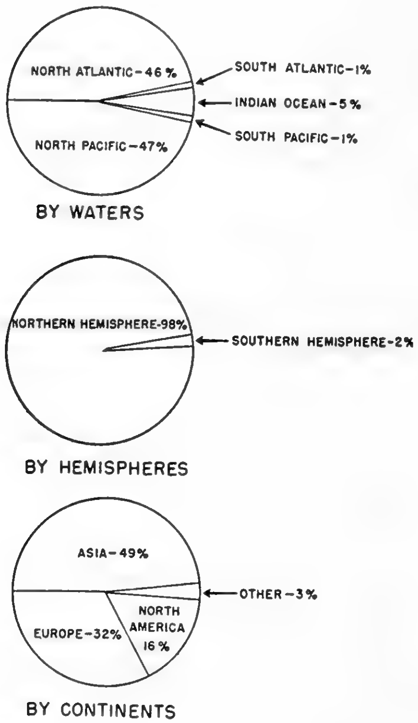


FIG. 12–1. Distribution of world fishery production of 37 billion pounds before World War II.

(Courtesy U. S. Fish and Wildlife Service)

The major known fishery resources of the world are located, according to the Food and Agriculture Organization (Anon., 1945), as follows:

North America. *Atlantic:* Waters contiguous to South Greenland, Labrador, Newfoundland, the Maritime Provinces and other parts of eastern Canada, the Atlantic Coast of the United States, and the areas covered by Davis Strait, the Grand Banks, and the Gulf of Mexico.

Pacific: Waters contiguous to Panama, the areas covered by the Bering Sea and from the Gulf of Alaska to Lower California, and offshore Central America.

South America. *Atlantic:* Waters contiguous to Venezuela, the Guianas, Southern Brazil, Uruguay, Argentina, the Falkland Islands, and Tierra del Fuego.

Pacific: Waters contiguous to Peru, Chile, and the Galapagos Islands.

Asia. Waters contiguous to the Siberian Coast and the East Indies, and the areas covered by the Bering, Okhotsk, Caspian, Japan, and China Seas, and the Bay of Bengal.

Africa. Waters contiguous to the Atlantic Coast of South Africa and Angola, and the areas covered by the Gulf of Guinea, the waters in the region of the Cape Verde and Canary Islands, and the Mediterranean.

Europe. Waters contiguous to the coast of Norway, the Faroes, Shetlands, and Orkneys, Iceland, Jan Mayen, and Bear Island, and the areas covered by the Bay of Biscay, and the North, Baltic, Barents, Kara, and Black Seas.

Australia, New Zealand, East Indies. Waters contiguous to the central and southern New Zealand coasts, Tasmania, and the southern and eastern Australian coasts.

The greatest development of the world's fisheries has occurred where the resources have been abundant, markets for the product readily available, and the nations inclined toward maritime activities. As might be expected, the first signs of depletion have been noted in those areas where a combination of factors permitted intensive fishing, and in connection with those species whose reproductive cycle or habitat made them particularly susceptible.

Promise of greater development is most apparent in such southern hemisphere areas as South America, Africa, and Oceania. Asia also has possibilities. And, in all probability, we still have much to look forward to in the northern hemisphere in the way of new banks, migratory pelagic species, and even in the deeper untested waters.

Production by Countries

Accurate figures on world fisheries production are not available (Anon., 1945; Anon., 1948; Fiedler and Frank, 1944; Sandberg, 1945a). The best estimates indicate that in prewar years the catch amounted to about 37 billion pounds valued at about 1 billion dollars. These figures exclude whale products and an estimated 2 billion pounds of fish taken (a) for subsistence, (b) while angling, and (c) unrecorded as commercial production. Postwar production is estimated to be equal to or greater than the prewar volume, because the fisheries of most countries have returned at least to normal and in some there have been expansions. If the value of the postwar catch tripled in all countries, as it did in the United States, world production in 1948 would be worth about 3 billion dollars at the fishermen's level.

The first fifteen countries listed in Table 24 and Figure 12–2 produce about 90 per cent of the world catch (Sandberg, 1945a). Japan remains the principal fishing nation. In 1938 it landed 3,078,344 metric tons, not including 442,714 tons of seaweed. Preliminary figures for 1948 still indicated that it held the leading position, with 2,085,760 metric tons (Anon., 1949a). The 1948 production came only from the greatly curtailed area to which Japanese fishing was limited by the Supreme Commander for the Allied Powers, and excluded unreported landings estimated at about 15 per cent or 368,074 tons. The United States production was next largest in 1948, with an estimated 2,075,220 metric tons. Its fisheries have apparently been second to those of Japan in volume since about 1934. The fisheries of the U.S.S.R., China, and Korea have been large, but recent reliable data on the catch have not been available.

Table 25 includes information from a number of sources on the fisheries of nearly 100 countries of the world (Sandberg, 1945a). As might be expected, data on the number of fishermen and fishing craft is less adequate than information on the volume or value of the fisheries. Much more accurate world fishery statistics are being obtained, however, as a result of the efforts of FAO's Division of

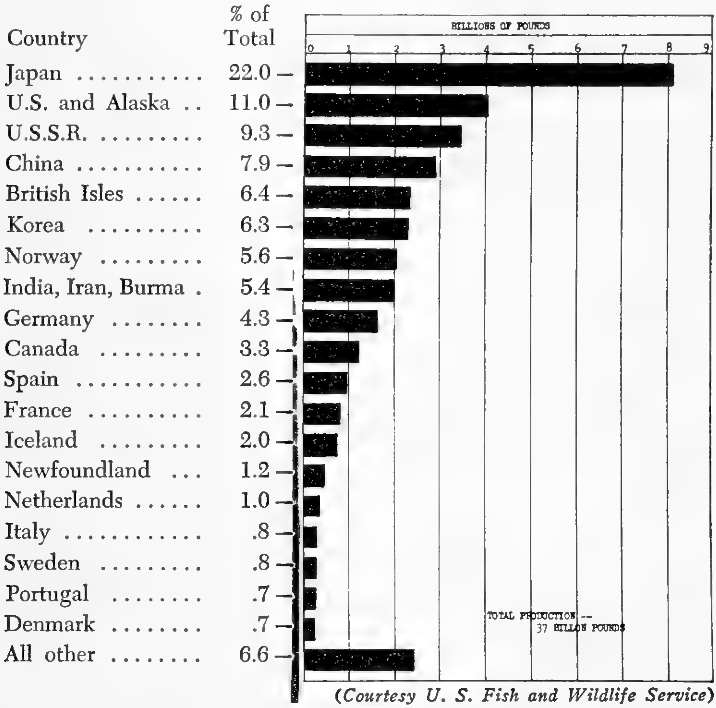
TABLE 24. FISHERMEN, FISHING CRAFT, AND PRODUCTION OF PRINCIPAL COUNTRIES PRIOR TO WORLD WAR II.

Country	Year	No. Fishermen Engaged	No. Fishing Craft	Quantity (Thousands of pounds)	Value (Thousands of dollars)	Remarks
Japan	1936	1,102,502	366,267	8,107,816	100,807	—
U. S. and Alaska	1940	124,795	71,810	4,059,524	98,957	—
U.S.S.R.	1938	250,000	—	3,432,000	82,368	Fishermen are for 1933. Value estimated.
China	1939	—	—	2,890,000	20,000	Estimated.
British Isles	1938	—	—	2,335,531	80,835	Quantity does not include shellfish.
Korea	1939	—	—	2,300,000	24,000	Quantity estimated.
Norway	1939	115,000	74,580	2,041,620	24,091	—
India, Iran, Burma	1932	—	—	2,000,000	20,000	Estimated.
Germany	1938	30,000	20,000	1,596,919	41,518	Fishermen and craft estimated. Includes salt-water species only.
Canada	1941	63,745	37,708	1,198,865	29,909	—
Spain	1940	195,000	40,000	967,252	68,275	Fishermen and craft estimated.
France	1937	73,989	23,201	788,400	45,537	—
Iceland	1942	5,003	708	740,514	16,264	Fishermen and craft are for 1943. Value estimated.
Newfoundland	1937	34,458	—	450,000	8,000	Quantity excludes whales and seals. Value for mfg. products and includes whales and seals.
Netherlands	1939	17,570	3,443	350,367	8,492	Estimated.
All other	—	—	—	3,521,096	164,882	—
Grand Total	—	—	—	36,779,904	833,935	

Source: Sandberg, U. S. Fish and Wildlife Service (1945).

Fisheries in the international field (Anon., 1948; Anon., 1949a). The most recent available production data are shown in Table 27.

The importance of a country's fisheries, particularly in its own economy, is measured more accurately by per capita production than by total catch. Using



(Courtesy U. S. Fish and Wildlife Service)

FIG. 12–2. Commercial fishery production of the world prior to World War II.

this yardstick, one finds in Table 26 that relatively small countries—Iceland, Newfoundland, and Norway—rank far higher than larger producers and more populous countries.

Production by Species

Herring and similar species are undoubtedly the most important in volume of all the varieties of fish making up the world's production. Norway, alone, for example, landed 1,032,843 metric tons of herring in 1948 (Anon., 1945c). The salmon are probably the most valuable. There are no detailed data on world production by species. The most important fisheries, however, include the following:

Demersal Species: Bottom-Dwelling. Cod and related species, such as haddock, hake, cusk, and pollock (usually called "ground fish" or "whitefish"). Flatfish, such as sole, flounders, and halibut. Rosefish and related species. Mollusks, such as oysters, clams, and mussels. Crustacea, such as shrimp, crabs, and lobsters.

Pelagic Species: Surface-Swimming. Herring and similar species, such as pilchards, anchovies, sprat, and menhaden. Tuna and tunalike species, such as

TABLE 25. FISHERMEN, FISHING CRAFT, AND PRODUCTION BY CONTINENTS AND COUNTRIES PRIOR TO WORLD WAR II.

Continent and Country	Year	No. Fishermen Engaged	No. Fishing Craft	Quantity (Thousands of pounds)	Value (Thousands of dollars)	Remarks
North America:						
Canada	1941	63,745	37,708	1,198,865	29,909	—
Central America and West Indies:						
Bahamas (British)	1936	390	65	1,275	112	—
Barbados (")	1940	1,900	536	1,000	100	—
British Honduras	1940	—	—	500	50	Estimated
Costa Rica	1940	—	—	1,000	60	Estimated
Cuba	1940	—	—	15,000	1,200	—
Dominican Republic	1940	—	—	1,000	40	Estimated
Dutch West Indies	1940	—	—	1,000	60	Estimated
El Salvador	1940	—	—	700	28	Estimated
French West Indies	1940	—	—	9,000	540	Estimated
Guatemala	1940	—	—	100	4	Estimated
Haiti	1940	—	—	2,000	80	Estimated
Honduras	1940	—	—	300	12	Estimated
Jamaica (British)	1940	1,200	400	10,000	800	Estimated
Leeward and Windward Islands (British)	1940	1,437	327	3,600	350	Estimated Men and craft for Leeward Is. only.
Nicaragua	1940	—	—	300	12	Estimated
Panama	1940	—	—	3,000	240	Estimated
Puerto Rico	1940	1,403	716	3,080	207	—
Trinidad and Tobago (British)	1940	2,870	948	6,000	600	Estimated
Virgin Islands (British)	1940	200	72	160	13	Value estimated
" " (United States)	1940	405	186	616	49	—
Greenland	1937	—	—	6,678	204	Includes exports only.
Mexico	1940	—	2,195	155,141	6,887	The 1941 production reported at 109,981,000 lbs., valued at $4,990,029.
Newfoundland	1937	34,458	—	450,000	8,000	Quantity excludes whales and seals. Value for mfg. products and includes whales and seals.
St. Pierre and Miquelon	1942	—	144	1,638	197	Includes salted green fish only.
United States and Alaska	1940	124,795	71,810	4,059,524	98,957	The 1943 production estimated at 4 billion lbs., valued at 180 million dollars.
Total, North American countries		—	—	5,931,477	148,711	

South America:						
Argentina	1940	2,000	824	121,122	3,125	The 1942 production reported at 126,784,000 lbs. Fishermen and craft for 1933.
Brazil	1940	80,002	31,300	134,252	5,584	Fishermen and craft for 1938. The 1943 production estimated at 176 million lbs.
British Guiana	1940	692	384	500	50	Estimated
Chile	1942	5,617	2,410	70,869	3,543	Value estimated
Colombia	1940	—	—	3,500	210	Estimated
French Guiana	1940	—	—	1,792	170	Estimated
Peru	1940	6,568	2,404	26,097	365	—
Surinam (Dutch Guiana)	1940	—	—	3,748	200	Estimated
Uruguay	1934	313	—	6,677	135	Fishermen are for 1940. The 1940 production reported at 7,334,000 lbs.
Venezuela	1940	—	—	100,000	3,000	Estimated
TOTAL, South American countries		—	—	468,557	16,382	
Asia:						
Arabia	1936	—	—	2,003	86	Exports only
British Malaya	1940	27,069	11,167	196,768	10,350	Value estimated
Ceylon	1935	1,493	6,959	1,800	74	Estimated
China	1939	—	—	2,890,000	20,000	Estimated
Chosen (Japan)	1939	—	—	2,300,000	24,000	Quantity estimated
Hawaii	1937	4,000	999	19,706	1,501	Fishermen, craft and value estimated
India, Iran, Burma	1932	—	—	2,000,000	20,000	Estimated
Indo-China	1937	—	—	79,638	3,059	Includes exports only
Japan	1936	1,102,502	366,267	8,107,816	100,807	—
Kwangtung Leased Territory	1937	305,000	—	132,704	4,673	—
Palestine	1940	1,663	530	3,821	252	Fishermen and craft for 1941. The 1942 production reported at 3.9 million lbs., valued at $568,000
Philippines	1938	—	—	178,055	10,544	—
Thailand (Siam)	1935	—	—	44,316	795	Includes exports only
U.S.S.R. (Asia only)	1938	—	—	2,127,840	51,068	Value estimated
Total, Asiatic countries		—	—	18,084,467	247,209	

TABLE 25. FISHERMEN, FISHING CRAFT, AND PRODUCTION BY CONTINENTS AND COUNTRIES PRIOR TO WORLD WAR II (*Continued*).

Continent and Country	Year	No. Fishermen Engaged	No. Fishing Craft	Quantity (Thousands of pounds)	Value (Thousands of dollars)	Remarks
Europe:						
Belgium	1938	1,784	445	86,254	4,216	Fishermen and craft for 1936.
Bulgaria	1940	—	—	15,871	2,380	Value estimated
British Isles:						
England and Wales	1938	—	—	1,711,704	59,945	Quantity does not include data on crabs, lobsters, and oysters.
Scotland	1938	—	—	592,938	18,751	"
Ireland	1941	8,865	3,137	30,889	2,139	"
Czechoslovakia	1937	—	—	6,500	390	Value estimated
Danzig	1931	2,100	811	6,303	350	—
Denmark	1940	—	15,350	250,800	10,904	Craft for 1937.
Estonia	1935	—	—	40,477	602	The 1943 production reported at 22 million lbs.
Faroe Islands	1938	2,930	1,850	55,100	1,408	Estimated
Finland	1933	—	—	79,362	2,381	—
France	1937	73,989	23,201	788,400	45,537	—
Germany	1938	30,000	20,000	1,596,919	41,518	Fishermen and craft estimated. Includes salt-water species only.
Greece	1937	6,860	2,015	39,537	3,817	Fishermen and values estimated. The 1938 production reported at 51 million lbs.
Iceland	1942	5,003	708	740,514	16,264	Value estimated. Fishermen and craft are for 1943.
Italy	1937	108,000	42,051	304,000	26,000	Fishermen estimated
Latvia	1932	3,907	524	29,752	324	—
Lithuania	1938	—	—	5,788	203	—
Maltese Islands	1938	1,300	700	2,380	265	—
Netherlands	1939	17,570	3,443	350,367	8,492	Estimated
Norway	1939	115,000	74,580	2,041,620	24,091	The 1942 production reported at 1½ billion lbs.
Poland	1937	1,822	953	30,822	974	—
Portugal	1940	36,837	13,630	260,588	11,926	Fishermen are for 1941. The 1941 production reported at 403.5 million lbs., valued at $21,613,000.
Rumania	1938	—	—	79,738	4,183	The 1942 production reported at 89,621,000 lbs., valued at $4,705,000.

Spain	1940	195,000	40,000	967,252	68,275	The 1943 production reported at 979 million lbs., valued at $98,230,000. Fishermen and craft estimated.
Sweden	1939	23,114	20,378	292,866	7,830	The 1941 production reported at 249.4 million lbs., valued at $17,055,000.
Switzerland	1942	135	—	631	214	—
Turkey	1935	—	—	51,000	1,525	Quantity estimated
U.S.S.R. (Europe only)	1938	—	—	1,304,160	31,300	Value estimated
Yugoslavia	1936	18,294	6,293	14,300	690	The 1938 production reported at 17,635,200 lbs.
TOTAL, European countries		—	—	11,776,832	396,894	
Africa:						
Algeria	1936	3,609	1,081	44,780	3,162	—
Angola (Portugal)	1936	—	—	31,517	480	Includes sardines only.
Belgian Congo	1928	—	—	23,681	540	Includes exports only.
Canary Islands	1931	2,500	250	11,638	1,450	Quantity and value estimated.
Cyrenaica	1928	—	—	11,758	353	Includes sponges, sardines, and tuna only. Value estimated
Egypt	1938	52,800	10,022	70,767	4,055	—
French Morocco	1933	2,323	511	42,580	1,264	—
French West Africa	1935	—	—	23,212	172	—
Kenya	1931	—	—	10,988	167	Includes exports only.
Morocco (Spanish and Intern. Zone)	1933	—	—	30,864	484	—
Seychelles	1925	600	350	1,560	61	—
Southwest Africa	1934	—	—	6,000	400	Estimated
Tripoli	1934	—	—	1,910	220	Includes tuna only.
Tunisia	1937	10,820	3,130	23,346	1,397	—
Union of South Africa	1936	7,400	—	60,000	2,500	Fishermen estimated
TOTAL, African countries		—	—	394,601	16,705	
Oceania:						
Australia	1939	9,081	5,462	72,732	5,850	—
Fiji Islands	1931	—	—	2,838	234	—
New Zealand	1939	2,218	1,279	48,400	1,950	The 1943 production reported at 35 million lbs., valued at $1,420,000.
TOTAL, Oceanic countries		—	—	123,970	8,034	
GRAND TOTAL		—	—	36,779,904	833,935	

Source: Sandberg, U. S. Fish and Wildlife Service (1945a).

TABLE 26. FISHERY PRODUCTION PER PERSON IN CERTAIN COUNTRIES.

Country	Pounds
Iceland	6,223
Newfoundland	1,525
Norway	680
Japan	111
Canada	109
Chosen	100
Kwantung Leased Territory	67
Denmark	63
Sweden	49
United Kingdom	48
British Malaya	39
Netherlands	39
Portugal	37
Spain	37
United States and Alaska	35
Venezuela	33
Germany	20
France	20
Soviet Union	18
Philippine Islands	11
Argentina	9
Mexico	8
Italy	7
China	6
India, Iran, Burma	5
Brazil	3

Source: Anon., Food and Agriculture Organization (1945).

yellowfin and bluefin tuna, albacore, skipjack, bonito, and yellowtail. Mackerel and related species. Sharks and sharklike species.

Anadromus Species: Migrate from the Sea to Fresh Water to Spawn. Salmon, shad, and smelt.

Catadromus Species: Migrate from Fresh Water to the Sea to Spawn. Eels.

The relative importance of the above species in some of the countries for which there are statistics may be noted in Table 27 (p. 204).

Utilization of Catch

About two-thirds of the world catch is marketed as fresh, frozen, canned, or cured fishery products for human food. The remaining one-third is reduced to fish meal and oil. Of the portion destined for human consumption about 40 per cent is edible (Anon., 1945).

Only rough estimates can be made of the world's production of processed fishery products (Fiedler and Frank, 1944, Anon., 1945). It has been calculated, however, that about 2 billion pounds of canned fish and about 3 billion pounds of cured fish (dried, salted, and smoked) were produced from an annual catch of 39 billion pounds. Canned fish represented perhaps 4 billion pounds and cured fish about 6 billion pounds. A significant part of the catch—as well as processing

waste—was utilized to produce fish meal and fish oil. The catch used directly for reduction purposes was estimated as about 13 billion pounds. The remainder of the catch—16 billion pounds—was marketed as fresh or frozen products (Fig. 12–3). The trend since about 1940 has been increasingly toward frozen fishery products,

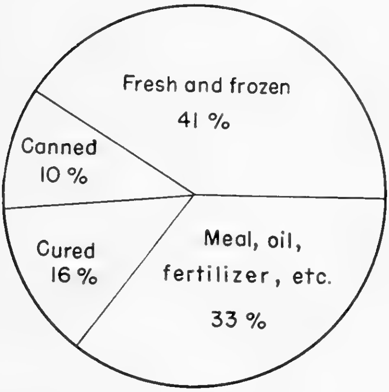


FIG. 12–3. Estimated utilization of world catch of fishery products.

but even in 1948 it is doubted that they represented more than 600 million pounds of the world catch. Tables 28, 29, and 30 show canned, cured, and other production in greater detail.

Foreign Trade

Prior to World War II probably 5 billion pounds of the 37 billion pound catch entered world trade. Cured fish constituted the most important export item, followed by fresh and frozen fish and the preserved products (canned or similar processing). In exported form the value has been estimated at $250,000,000 (Fiedler and Frank, 1944). For the year nearest to 1938 for which figures are available 61 countries reported exports of 1,844,096 and imports of 2,075,500 metric tons (Anon., 1948).

Preliminary postwar data indicate that exports of fresh and frozen fishery products and preserved fishery products have increased in volume, while exports of cured products and mollusks and crustaceans have declined. Data on oils, fish meals, and fertilizers are not fully available, but it is believed that exports of these products have not recovered to prewar totals (Anon., 1948). Prewar and postwar trade are compared in Table 31 (p. 208).

Some countries with a heavy per capita production, as Iceland, Newfoundland and Norway, must export in volume. Their exports consist largely of ground fish and herring. Other countries export expensive processed specialties, such as canned sardines, anchovies, and tuna, and import less expensive staples, such as salted cod. This is particularly true of Portugal, Italy, and some South American countries.

During and since World War II increased production in some countries forced development of wider markets. The United States has received an important part of the increased exports, in some instances largely because of a need for dollars on the part of the exporting country.

Although trade in fishery products amounts to only a very small part of total

TABLE 27. LANDINGS OF GROUPS OF SPECIES BY

Country	Year	Total	Teleostean fresh-water species	Salmon and allied species	Teleostean flatfishes
Australia	1947	40,700	...	...	...
Austria	1947	100	100	—	—
Belgium	[c] 1948	70,890	...	—	10,944
Brazil	1947	126,700	...	...	...
Canada	1948	643,928	36,110	65,341	20,299
Ceylon	1948	(20,000)	...	...	...
Chile	1947	66,993	—	—	376
Costa Rica	1948	433	—	—	—
Czechoslov.	1947	3,490	3,490	—	—
Denmark [d]	1948	223,500	500	2,300	62,500
Ecuador [e]	1948	22,356	2,236	447	671
Egypt	1946	42,000	4,500	—	—
Faroe Is.	1948	(80,000)	...	...	...
Finland	1948	46,000	17,000	450	10
France [f]	1948	434,600	—	—	[g]
Germany (Bizone)	1948	380,200	...	...	...
Honduras	1948	77	—	—	—
Iceland	1948	464,688	—	147	7,957
Ireland	1948	23,101	165	1,118	1,035
Italy	1947	132,500	7,000	—	—
Japan	[i] 1948	2,085,760	7,540	12,053	88,818
Lebanon	1948	1,440	—	—	—
Malayan Union	1947	41,800	...	...	...
Netherlands	1948	269,440	6,650	1	25,000
Newfoundland [j]	[k] 1948	374,930	—	3,209	1,162
New Zealand	1946	32,047	[l]	—	2,565
Norway	1948	1,454,134	—	1,200	6,600
Pakistan [m]	1948	22,581	8,503	1,098	801
Peru	1946	27,657	—	—	67
Philippine Islands	1947	79,726	—	—	—
Poland	1948	48,204	—	416	566
Portugal	1948	271,175	622	1	405
Siam	1947	161,024	37,939	—	—
Spain	1948	533,100	...	...	...
Sweden	1948	230,735	14,000	[n]	4,704
United Kingdom [p]	1948	1,195,682	—	1,931	74,410
Union of S. Africa	1948	28,900	...	...	...
U. S., Alaska	1947	2,345,100	76,200	226,100	73,000
Uruguay	1947	3,500	...	...	...
Venezuela	1947	40,900	...	...	...

Note: ... Not available.
— Nil
( ) Estimated.

[a] Round fresh weight.

[b] Composed of seaweed, sea urchins, coral, lichen, terrapin, turtles, bloodworms and sandworms, frogs, trepang, and sponges. However, the figures for the countries listed do not necessarily include every one of these items. For Poland, listed as "Other teleostean marine species". Metric ton = 2,204.6 pounds.

[c] Includes landings in foreign ports.

[d] Faroe Islands and Greenland not included.

[e] Estimated; probably includes subsistence fishing.

[f] Metropolitan France only.

[g] Flatfish and sharks included with "Other teleostean marine species".

CERTAIN COUNTRIES, 1946–1948 (IN METRIC TONS[a]).

Cod, hake, and allied species	Herring and allied species	Tunas, true mackerels, and allied species	Other teleostean marine species, including ganoids	Elasmobranch fish (sharks, rays, etc.)	Crustaceans and mollusks	Miscellaneous[b]
...	...	...	...	...	...	...
—	—	—	—	—	—	—
22,792	24,785	623	2,530	7,364	1,802	—
...	...	...	...	...	...	...
176,089	282,089	13,182	11,362	140	35,771	3,545
...	...	...	...	...	...	...
25,076	4,348	7,927	14,050	883	14,333	...
—	—	400	33	—	—	—
—	—	—	—	—	—	—
55,700	30,200	10,500	53,200	2,300	6,300	—
...	1,118	4,471	6,706	2,236	4,471	—
—	5,500	—	31,500	500	—	—
...	...	...	...	...	...	...
100	21,000	—	7,440	—	—	—
79,800	96,600	28,800	[g] 186,000	[g]	43,400	...
...	...	...	...	...	...	...
—	—	—	73	—	4	—
281,444	150,122	—	24,738	280	—	—
5,061	4,022	7,407	936	1,179	2,178	—
—	[h] 37,000	[h] 12,200	71,000	—	7,500	—
162,727	408,504	156,732	602,528	90,397	492,034	64,427
80	640	300	270	150	—	—
...	...	...	...	...	...	...
13,000	150,000	5,600	5,939	250	63,000	—
308,228	51,707	1,622	4,002	—	5,000	—
947	127	27	[l] 19,192	145	9,044	—
354,500	1,032,843	13,300	10,513	24,720	10,458	—
560	550	151	650	1,510	8,758	—
—	341	19,951	6,522	776	—	—
—	—	4,036	62,404	58	3,568	...
35,294	7,184	728	1,600	3	—	2,413
101,975	79,987	3,587	69,191	4,273	11,134	—
—	—	29,055	20,694	1,850	71,486	—
...	...	...	...	...	...	...
59,968	100,694	8,718	[o] 42,651	[n]	[n]	—
733,926	274,850	8,151	42,733	33,032	26,649	—
...	...	...	...	...	...	...
161,200	723,500	201,000	269,100	17,200	596,300	1,500
...	...	...	...	...	...	...
...	...	...	...	...	...	...

[h] 1946
[i] Estimated to cover 85 per cent of landings.
[j] Newfoundland exports, plus an estimated quantity for domestic consumption.
[k] Including Labrador.
[l] Teleostean fresh-water species may be included with "Other teleostean marine species".
[m] West Pakistan only.
[n] Included with "Other teleostean marine species".
[o] Including salmon and allied species, tuna, sharks, crustaceans and mollusks. Also includes 12,672 tons of fish landed abroad, unavailable by species.
[p] Scotland, England and Wales, including the Isle of Man.

Source: Anon., Fisheries Division, Food and Agriculture Organization (1949c).

TABLE 28. WORLD PRODUCTION OF CANNED FISHERY PRODUCTS.

Rank	Country or Area	Year	Quantity (Thousands of pounds)
1	United States	1940	708,930
2	Japan	1939	309,400
3	Spain	1939	231,759
4	Canada	1941	188,146
5	Portugal	1942	[1]150,000
6	Norway	1941	110,230
7	France	1939	[1]30,000
8	U.S.S.R.	1942	[1]20,000
9	French Morocco	1942	[1]12,500
10	Italy	1939	[1]12,000
11	Brazil	1942	11,000
12	Other Latin America	—	31,100
13	Other Africa	—	7,548
14	Pacific Area and Oceania	—	5,437
15	All other	—	[1]100,000
	Total		1,928,050

[1] Estimated.

Source: Fiedler and Frank, United Nations Interim Commission on Food and Agriculture (1944).

TABLE 29. WORLD PRODUCTION OF CURED FISHERY PRODUCTS.

Rank	Country or Area	Year	Quantity (Thousands of pounds)	Remarks
1	U.S.S.R.	1942	500,000	Estimated
2	Norway	1941	418,875	—
3	Netherlands	1938	198,542	Exports
4	United Kingdom	1939	152,022	Exports
5	Canada	1941	143,028	—
6	Newfoundland and Labrador	1941	124,181	Exports
7	United States	1940	97,326	—
8	Argentina	1942	61,729	—
9	France	1938	46,369	Exports
10	Japan	1938	43,559	Exports
11	Iceland	1942	29,873	Exports
12	Venezuela	1942	25,000	—
13	Peru	1942	20,000	Estimated
14	Portugal	1941	14,515	Exports
15	Brazil	1941	14,000	Estimated
16	Sweden	1939	13,239	—
17	Spain	1941	11,700	Exports
18	St. Pierre and Miquelon	1937	8,724	Exports
19	Chile	1942	4,400	—
20	Union of South Africa	1941	3,207	Exports
21	Other Asia	1942	500,000	Estimated
22	Other Europe and Africa	1942	150,000	Estimated
23	Other Pacific Areas	1942	50,000	Estimated
24	Other Latin America	1942	10,000	Estimated
	Allowance for countries where exports are given	—	500,000	—
	Total		3,140,289	

Source: Fiedler and Frank, United Nations Interim Commission on Food and Agriculture (1944).

Table 30. Principal End Products in Certain Countries, 1946–1948 (in Metric Tons [a]).

Country	Year	Fresh and frozen fish	Salted and/or dried cod, hake, and allied species	Dried cod, hake, and allied species (stockfish)	Salted herring and allied species	Smoked herring and allied species	Canned salmon
Belgium	1948	29,899	—	—	12,102	—	—
Canada	1948	158,402	28,259	—	[b] 9,121	[b]	28,390
Chile	1947	40,492	658	—	...	53	—
Denmark	1948	100,500	1,800	...	[b] 8,000	[b]	—
Faroe Is. [c]	1948	...	13,200	—	...	...	...
Greenland	1948	...	(5,000)	...	...	...	...
France [d]	1948	287,260	29,400	...	—	—	—
Iceland	1948	165,877	13,400	6	11,480	—	—
Ireland	1948	1,563	468	—	1,593	—	—
Italy	1948	139,000	—	...	10,000	...	...
Japan	1947	[f] 1,503,400	7,313	1,125	[g] 69,750	—	188
Netherlands	1948	71,029	85	—	74,000	25,000	—
Newfoundland [i]	1948	20,646	64,429	—	[b] 19,564	[b]	125
Norway	1948	272,844	55,000	8,500	126,700	—	—
Pakistan [j]	1948	[k] 2,746	165	...	108	...	...
Philippine Republic	1948	[l] 52,787	...	...	[b] 1,462	[b]	...
Portugal	1947	97,451	23,267	—	1,033	—	—
Spain	1947	94,800	(20,000)	...	...	...	...
St. Pierre and Miquelon	1948	...	1,009	...	...	...	...
Sweden	1947	94,800	2,000	...	17,400	...	...
United Kingdom [m]	1948	656,847	[n] 258	—	44,887	69,599	...
U. S. and Alaska	1948	[p] 571,990	1,000	—	[e] 6,300	[e] 1,770	105,219

Country	Year	Canned herring and allied species	Canned tunas, true mackerels, and allied species	Cod oil, including liver oil	Herring oil, including allied species	Shark oil, including liver oil	Herring meal including allied species	Other fish meal
Belgium	1948	979	—	88	—	—	101	633
Canada	1948	21,004	1,312	1,433	12,025	1,000	30,755	9,973
Chile	1947	591	1,232	1	27	25	267	195
Denmark	1948	2,700	1,200	200	10	...	30	13,570
Faroe Is. [c]	1948	...	...	...	...	...	...	...
Greenland	1948	...	...	...	...	...	...	...
France [d]	1948	12,980	10,980	910	—	—	—	—
Iceland	1948	[e] 61	—	8.970	17,450	—	22,900	5,000
Ireland	1948	460	—	—	—	—	—	—
Italy	1948	4,000	3,000	...	...	...	...	...
Japan	1947	563	488	375	2,250	[h] 410	3,375	750
Netherlands	1948	4,500	160	—	—	—	[e] 7,200	[e] 690
Newfoundland [i]	1948	303	1	2,003	533	—	953	1,402
Norway	1948	27,700	1,900	7,700	40,000	770	110,000	13,505
Pakistan [j]	1948	...	...	...	...	...	...	...
Philippine Republic	1948	149	...	...	...	1	...	25
Portugal	1947	37,536	[h] 1,997	490	[h] 1,424	—	—	—
Spain	1947	...	...	...	...	...	...	...
St. Pierre and Miquelon	1948	...	...	...	...	...	...	...
Sweden	1947	11,000	1,000	...	...	...	...	...
United Kingdom [m]	1948	10,571	—	[e] 11,298	483	...	[o]	[o] 43,129
U. S. and Alaska	1948	93,932	[q] 89,530	752	51,148	1,500	127,897	52,359

Note: ... Not available.
— Nil.
( ) Estimated.

[a] Product weight. Metric ton = 2,024.6 pounds.
[b] Smoked herring included with salted herring.
[c] Faroe Islands and Greenland not included.
[d] Metropolitan France only.
[e] 1947.
[f] Landed weight.
[g] Salted and dried.
[h] 1946.
[i] Includes Labrador in 1948.
[j] West Pakistan only.
[k] Fresh only.
[l] Excludes frozen fish fillets.
[m] Scotland, England, and Wales.
[n] All ground fish ("demersal fish").
[o] Herring meal included with other fish meal.
[p] Includes 409,601 fresh as round weight (Fish and Wildlife Service estimate).
[q] Including jack mackerel.

Source: Anon., Fisheries Division, Food and Agriculture Organization (1949C).

TABLE 31. FOREIGN TRADE IN FISHERY PRODUCTS FOR CERTAIN COUNTRIES, 1938 AND 1946 (OR NEAREST YEARS) (IN METRIC TONS [1]).

Country	Year	Fish: Fresh or frozen		Fish: Dried, salted, or smoked		Fish: Canned		Crustaceans and Mollusks		Fish oils		Fish meals and fertilizers		Miscellaneous animal and plant products		Total	
		Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Algeria	1938	1,131	498	521	3,194	1,034	2,076	1,880	45	52	*	—	—	10	3	4,628	5,816
	1940	22	318	821	5,673	1,194	1,483	366	28	62	8	—	—	2	3	2,467	7,513
Angola	1934	5	45	353	6,197	65	521	3	—	—	19	—	—	2	—	428	6,782
Argentina	1938	[2] 921	[2] 95	5,620	[3] 271	2,706	[3]	[2] 514	[2]	284	309	—	—	13	2,485	10,058	3,160
	1943	[2] 147	[2] 142	31	[3] 1,468	52	[3]	[2] 25	[2]	42	343	—	1,314	2	3,502	299	6,769
Australia	1938/39	4,236	16	413	46	13,144	[4] 2	477	11	—	—	—	—	2,076	[5] 3,325	20,346	3,400
	1943/44	967	4	1	1	5,874	[4] 972	39	—	—	—	—	—	753	[5] 170	7,634	1,147
Austria	1938	1,545	9	1,234	*	[2] 2,114	*	5	30	1,076	4	—	—	—	—	5,974	43
	1947	7,067	8	3,806	—	[2] 564	—	5	—	132	—	—	—	—	—	11,574	8
Bahamas	1938	...	—	10	—	...	—	—	[7] 494	—	—	—	—	...	420	[6] 10	[6] 924
	1942	...	—	2	—	...	—	—	[7] 322	—	—	—	—	...	42	[6] 2	[6] 364
Belgium	1938	[2] 15,743	[2] 5,257	[2] 23,420	[2] 730	[2] 10,220	[2] 1,401	19,734	3,621	7,617	489	12	206	[8] 22,185	[8] 10,556	98,931	22,260
	1946	18,807	1,594	18,268	5,353	13,466	141	23,083	46	—	—	466	—	—	—	74,090	7,134
Bermuda	1938	30	—	205	—	[9] 631	—	[9] 99	—	—	—	—	—	[9] 1	—	[10] 235	—
	1942	9	—	86	—	[9] 514	—	...	—	—	—	—	—	—	—	[6] 609	—
Bolivia	1938	[11]	—	[11] 304	—	[2] 913	—	...	—	...	—	—	—	3	—	[6] 220	—
	1946	[11]	—	[11] 133	—	[2] 551	—	...	—	...	—	—	—	10	—	[6] 694	—
British Guiana	1936	[12] 8	—	[12] 283	—	[12] 208	—	—	—	—	—	—	—	[12] 1,764	—	2,263	—
Bulgaria	1938	952	—	1,120	—	64	*	—	—	—	—	—	—	1	—	2,137	*
Canada	1938	8,656	49,870	2,828	43,326	[13] 1,797	27,449	1,590	9,008	1,415	14,165	...	19,518	[14] 12,323	4,388	[6] 28,609	[6] 167,724
	1946	11,895	106,630	2,734	48,672	[13] 143	67,786	977	11,508	852	2,023	260	29	[15] 32,947	502	[6] 49,808	[6] 237,150
Ceylon	1938	23	—	23,823	31	977	—	—	—	21	—	6,522	*	88	[16] 16	31,454	47
	1946	2	—	30,198	43	271	—	—	—	23	—	1,857	—	32	[16] 261	32,283	304
Chile	1938	—	62	[2] 117	1	[2] 394	1	[2]	48	73	—	—	—	112	32	696	144
	1946	—	345	11	729	[2] 88	558	[2]	40	45	—	—	—	4	10	148	[6] 1,682
China	1938	6,299	3,275	31,876	1,588	...	...	1,690	2,375	...	—	—	—	18,204	861	[6] 58,069	[6] 8,099
	1940	12,932	1,004	30,816	6,060	...	...	2,978	1,620	231	—	—	—	28,237	215	[6] 75,194	[6] 5,899
Colombia	1938	—	—	—	—	943	—	37	—	11	*	—	—	1,193	1	2,184	1
	1944	*	4	—	—	435	—	5	*	57	—	—	—	3	—	500	4
Costa Rica	1938	1	3,363	220	—	468	—	40	—	14	—	—	—	3	143	746	3,506
	1946	—	1,280	48	—	173	321	41	—	11	—	—	—	*	232	273	1,833
Cuba	1938	63	4	8,900	[3] 7	2,924	[2] 1	348	171	—	—	—	—	188	[17] 444	12,423	627
	1940	66	63	5,853	[3] 15	2,279	[2] 1	440	268	—	—	—	—	160	[17] 722	8,798	1,069
Denmark	1938	14,298	49,945	9,030	2,125	510	391	[2] 259	[2] 2,420	11,287	1,830	3,350	—	35,760	—	74,494	56,711
	1946	1,745	82,295	5,242	4,825	65	251	[2] 81	[2] 7,851	1,373	513	3,188	—	5,446	—	17,140	95,735
Dominican Republic	1938	1	—	1,941	—	124	—	—	—	...	—	—	—	—	—	[6] 2,068	—
	1946	*	—	903	—	55	—	—	—	...	—	—	—	—	—	[6] 958	—

Egypt	1938	5	715	5,607	14	741	—	2,030	6	745	—	—	—	[18] 156	31	[6] 9,284	766
	1944	—	341	123	6	595	*	308	13	140	*	—	—	[18] 6	6	[6] 1,172	366
Finland	1938	311	1,492	3,174	1,737	90	30	55	70	—	—	—	—	884	—	4,514	3,329
	1946	1,236	29	6,274	5	16	1	4	95	—	—	—	—	[19] 354	—	7,884	130
Formosa	1938	—	680	23,698	329	—	—	*	50	—	—	—	—	[20] 11	41	23,709	1,100
France	1938	15,362	14,125	10,195	21,492	22,055	5,187	25,460	6,466	3,258	181	—	—	720	1,063	[6] 77,050	48,514
	1943	26	22	589	25	1,837	12	*	—	709	—	—	—	1	6	[6] 3,162	65
French Morocco	1938	112	[21] 1,802	347	1,356	113	13,809	200	30	278	160	—	...	607	788	1,657	[6] 17,945
Germany	1938	151,178	2,211	61,812	1,241	15,010	434	1,168	87	—	—	89,811	1,927	[2] 644	[2] 167	[6] 319,623	6,067
Gold Coast	1938	30	—	2,660	—	3,442	—	—	—	—	—	—	—	—	—	6,132	—
	1944	—	—	447	—	568	—	—	—	—	—	—	—	—	—	1,015	—
Greece	1938	5,442	140	16,905	48	—	—	—	—	—	—	—	—	2,907	48	25,234	236
	1944	4,570	43	6,825	19	—	—	—	—	—	—	—	—	1,266	20	12,661	82
Hungary	1938	5	965	5	—	476	—	2	—	[22] 803	—	—	—	[23] 1,948	*	3,239	965
Iceland	1938	—	17,430	—	80,248	10	16	*	62	...	27,920	—	22,294	2	1,947	[6] 12	[6] 149,917
	1944	...	96,711	—	28,768	*	514	—	—	—	25,289	—	16,364	*	70	[6] *	167,716
Indo-China	1938	1	542	127	32,275	398	—	162	2,267	—	—	—	—	63	1.231	751	36,315
Ireland	1938	6,590	1,122	1,360	460	986	—	27	2,835	254	—	—	—	2,787	...	12,004	[6] 4,417
	1946	939	3,242	228	1,131	286	—	6	3,340	—	—	—	—	1	524	1.460	8,237
Italy	1938	12,692	567	80,299	1,164	5,455	2,050	186	171	*	—	—	—	55	23	98,687	3,975
	1946	4,594	4	34,178	42	10,019	15	*	5	...	...	—	—	...	...	[6] 48,791	[6] 66
Jamaica	1938	10	—	12,676	—	730	—	—	—	—	—	—	—	...	2	[6] 13,416	2
	1945	4	—	11,155	—	881	—	—	—	—	—	—	—	—	*	12,040	*
Japan	1938	...	[2] 16,364	7,567	[2] 22,262	—	88,746	—	12,964	—	45,596	—	—	6,428	27,591	[6] 13,995	213,523
Kenya and Uganda	1938	[24] 41	56	[24] 673	700	80	—	[2]	—	—	—	—	—	6	120	800	876
	1944	[24] 5	14	[24] 647	1,435	111	*	[2]	—	—	—	—	—	11	211	774	1,660
Leeward Islands	1938	—	—	179	4	34	—	—	—	—	—	—	—	914	13	1,127	17
Madagascar	1938	—	3	120	2	—	...	—	—	—	—	—	—	2	62	122	[6] 67
Malaya	1938	5,161	52	51,956	52,965	[2] 3,776	[2] 1,453	—	[2]	—	—	—	—	525	726	61,418	55,196
Manchuria	1937	11,979	936	38,019	166	3,182	—	1,119	...	56	—	—	—	22,378	—	76,733	[6] 1,102
Mexico	1938	14	5,526	[2] 394	148	1,036	1,534	12	3,719	—	—	—	—	37	292	1,493	11,219
	1946	21	67,315	[2] 637	90	796	—	152	6,257	—	...	—	132	*	7	1,606	[6] 73,801
Netherlands	1938	4,394	20,700	3,254	76,741	4,019	554	[25] 1,693	[25] 46,118	—	—	23,363	942	74,169	50,488	111,184	195,543
	1946	2,433	6,438	1,211	14,869	1,040	1,359	[25] 211	[25] 23,376	—	—	3,934	125	8,662	36	17,491	46,203
Newfoundland	1938	—	5,095	—	67,124	—	19	—	1,256	—	5,005	—	284	—	[26] 3,490	—	82,273
	1946	—	17,321	—	82,563	—	600	—	1,400	—	3,995	—	1,103	—	[26] 5,299	—	112,281
New Zealand	1938	—	2,188	[27] 75	28	2,548	90	—	135	371	186	—	—	—	...	2,994	[6] 2,627
	1946	—	1,405	[27] 11	132	144	132	—	254	—	—	—	—	—	—	155	1,923
Nicaragua	1938	[2] 25	—	[2]	*	[2]	—	[2]	—	—	—	—	—	1	4	26	4
	1945	[2] 62	—	[2]	—	[2]	—	[2]	—	—	—	—	—	—	3	62	3
Nigeria	1938	[2] 5	—	[2] 10,365	—	[2] 402	—	[2]	—	—	—	—	—	—	—	10,772	—
	1944	[2] *	—	[2] 1	—	[2] 80	—	[2]	—	—	—	—	—	—	—	81	—
Norway	1938	3,108	120,070	4,288	110,142	19	25,419	[19] 36	3,410	12,039	32,421	6,691	80,472	[28] 48,135	11,234	74,316	383,168
	1946	214	80,787	1	180,684	2	25,902	—	1,438	1,531	19,766	—	10,254	[28] 369	16,489	2,117	335,320
Palestine	1939	[29] 2,010	16	1,910	*	1,428	2	—	—	41	—	382	—	[30] 41	—	5,812	18
	1943	696	—	2,515	—	508	*	—	—	3	—	433	—	[30] 72	—	4,227	*

TABLE 31. FOREIGN TRADE IN FISHERY PRODUCTS FOR CERTAIN COUNTRIES, 1938 AND 1946 (OR NEAREST YEARS) (IN METRIC TONS [1]) *Continued.*

Country	Year	Fish: Fresh or frozen		Fish: Dried, salted, or smoked		Fish: Canned		Crustaceans and Mollusks		Fish oils		Fish meals and fertilizers		Miscellaneous animal and plant products		Total	
		Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Paraguay	1938	—	—	14	—	[2] 56	—	2	—	—	—	—	—	1	—	73	—
	1941	—	—	1	—	[2] 15	—	—	—	—	—	—	—	*	—	16	—
Peru	1938	1,057	*	[3] 270	*	[2] 142	—	11	...	—	—	—	—	*	23	1,480	[6] 23
	1943	321	194	[3] 41	13	[2] 98	755	*	...	—	—	—	—	*	810	460	[6] 1,772
Poland	1938	11,836	166	55,072	47	607	20	10	176	...	—	—	—	[31] 6,847	[30] 19	[6] 74,372	418
Portugal	1938	5,797	565	38,083	7,582	31	34,388	—	[10] 1,070	—	—	—	2,027	2	2,000	43,913	47,632
	1945	591	595	10,071	4,613	26	37,664	—	[10] 333	—	1,288	—	29	1	2,774	10,689	47,296
Rumania	1938	234	33	[19] 7,151	[19] 3	[2] 463	—	—	—	664	—	—	—	64	—	8,576	36
	1942	110	73	1,058	[19] 3	[2] 8	—	—	—	—	—	—	—	—	—	1,176	76
Salvador	1937	—	—	—	—	[2] 102	[2] 1	—	[2]	—	—	—	—	—	—	102	1
	1947	—	—	—	—	[2] 286	[2] 1	—	[2]	—	—	—	—	—	—	286	1
Southwest Africa	1938	4	—	24	[32] 591	[2] 72	[2] 505	—	[2]	—	—	—	—	—	25	100	1,121
	1945	1	—	16	[32] 1,877	[2] 47	[2] 1,545	—	[2]	—	—	—	—	—	47	64	3,469
Spain	1940	6,821	676	16,500	937	[2] 659	[2] 8,439	3	[2] *	—	—	400	*	26	2	24,409	10,054
	1945	2,835	489	21,856	2,520	[2] 719	[2] 5,680	*	[2]	—	—	2,746	8	42	9	28,198	8,706
Sweden	1938	13,064	22,533	36,633	4,202	[2] 1,424	[2] 968	[2] 437	[2] 127	1,578	1,438	...	—	4,690	3	[6] 57,826	29,271
	1946	4,166	4,993	23,653	29,805	[2] 717	[2] 2,487	[2] 550	[2] 44	5,000	267	4,308	—	15,300	90	53,694	36,966
Switzerland	1938	2,710	390	709	1	2,819	1	129	*	—	—	—	—	129	116	6,496	508
	1946	2,564	227	875	183	1,600	8	123	5	—	—	—	—	20	85	5,182	508
Tanganyika	1938	...	...	736	1,096	35	—	—	145	—	—	—	—	12	15	[6] 783	[6] 1,256
	1944	*	2	603	309	29	—	17	37	—	—	—	—	—	—	649	348
Tangier	1938	—	4	83	6	3	138	1	...	2	...	—	...	*	11	89	[6] 159
Thailand	1938/39	...	593	[32] 1,434	26,508	686	—	—	—	—	—	—	—	—	—	[6] 2,120	27,101
	1946	*	5	[32] 175	4,851	11	—	—	—	—	—	—	—	—	—	186	4,856
Trinidad and Tobago	1937	[33] 66	[34] 2	2,535	1	442	—	—	—	—	—	—	—	379	—	3,422	3
	1941	[33] 44	[34] 1	2,208	—	832	—	—	—	—	—	—	—	355	—	3,439	1
Tunisia	1938	199	492	612	34	1,162	168	[10] 32	86	9	16	—	—	17	27	2,031	823
	1940	60	27	342	2	944	20	[10] 12	126	3	[4] —	—	—	10	1	1,371	176
Turkey	1938	—	12,255	1	2,335	3	29	*	8	164	117	—	—	12	54	180	14,798
	1940	—	22,834	*	2,127	2	51	—	1	9	768	—	—	5	29	16	25,810
Union of S. Africa [35]	1938	76	605	1,588	1,600	5,401	8	—	2,402	126	[36] 8	—	—	—	7,584	7,191	12,207
	1945	35	325	285	393	594	394	—	1,269	62	[36] 387	—	—	—	2,303	976	5,071
United Kingdom	1938	83,081	54,664	18,656	162,670	73,424	[2] 4,969	13,712	[2] 290	[37] 269,851	[37] 11,100	12,510	3,804	[38] 34,464	—	[6] 505,698	[6] 237,497
	1944	212,650	35	8,331	1	63,646	[2] 27	4,303	[2]	[37] 44,390	[37] 984	29,445	—	[38] 3,115	—	[6] 305,880	[6] 1,047
U. S. A.	1938	54,276	3,598	44,481	1,732	21,097	40,416	16,192	6,358	35,349	[39] 1,214	36,677	1,298	27,671	[39] 34,884	[6] 235,743	[6] 89,500
	1946	115,353	705	55,581	5,517	20,770	72,522	22,237	13,147	14,264	6,635	9,393	59	12,810	[40] 27,775	[6] 250,408	[6] 126,360
Yugoslavia	1938	16	1,959	501	1,019	2	57	*	59	[37] 763	—	—	—	2	1	[6] 1,284	[6] 3,095

... Not available.
— Nil.
* Negligible.

[1] Product weight = (1 metric ton = 2,240 lbs.)
[2] Some or all crustaceans and mollusks included with fish or miscellaneous products.
[3] Some or all canned fish included with fish dried, salted, or smoked.
[4] Excludes quantities of fish potted or concentrated.
[5] Excludes quantities of sponges and unset pearls.
[6] Excludes items for which data are unavailable or listed in numbers.
[7] Crustaceans only.
[8] Excludes quantities of unpolished real pearls, wrought fine pearls, and coral in their natural state.
[9] Quantity given in packages or numbers.
[10] Excludes quantities in packages or numbers.
[11] Fish, fresh included with dried, salted, or smoked.
[12] May include some crustaceans and mollusks.
[13] Excludes quantities of fish preserved in oil and other fish preserved or prepared, not available.
[14] Excludes quantities of ambergris, not available, and fur skins (undressed) listed in numbers and quantities of unmanufactured mother-of-pearl; tortoise and other shells; and sponges.
[15] Excludes quantities of fur skins (undressed) listed in numbers.
[16] Excludes quantities of shells, listed in numbers.
[17] Excludes quantities of turtles and tortoises given in numbers.
[18] Excludes quantities of real pearls listed in carats.
[19] Includes caviar.
[20] Includes some fish, crustaceans and mollusks, and aquatic products not elsewhere specified.
[21] Includes some dried, salted, or smoked fish.
[22] Oils and fats of fish, whales, and seals.
[23] Includes spermaceti and sperm oils.
[24] Excludes re-exports of imported merchandise.
[25] Includes oyster and mussel spat.
[26] Excludes quantities of seal skins listed in numbers.
[27] Includes frozen fish.
[28] Includes pelts not listed separately.
[29] Excludes quantities of live fish listed in numbers.
[30] Excludes quantities of pearl seeds and unset pearls, including waste pearls.
[31] Includes fish oil and fats.
[32] Includes some fresh fish.
[33] Includes turtles.
[34] Includes shellfish of Trinidad taking.
[35] Imports and exports to all countries, excluding Northern Rhodesia and South West Africa.
[36] Includes some animal oils.
[37] Aquatic animal oils.
[38] Excludes quantities of oysters (breeding) reported in numbers.
[39] Whale and sperm oil included with fish oil.
[40] Excludes quantities of pearl or shell buttons shown in gross.
Source: Anon., Fisheries Division, Food and Agriculture Organization (1948).

world trade, it is significant, nevertheless, because of the nature of the products and their importance to the economy of the exporting countries and the well-being of the importing countries. Of the world trade in foodstuffs, however, fishery products represent a more substantial percentage.

Per Capita Consumption

The per capita consumption of fishery products throughout the world is difficult to determine. About 5 pounds (2.25 kilos) on an edible weight basis has been suggested as a prewar figure (Technical Committee on Fisheries, 1945). A number of surveys have been made in various countries, but, unfortunately, the data reported can seldom be compared because of differences in survey methods. Frequently, the surveys do not even make clear whether the consumption figure is based on the landed weight, the marketed weight, or the edible weight of the products consumed. Comparisons, therefore, are fruitless in most instances and will remain unsatisfactory until FAO can encourage those conducting studies in this field to utilize uniform conversion factors and to report consumption on a common basis (Anon., 1949).

Tables 32, 33, 34, 35, 36, and 37 indicate that, of the North American countries, Canada and the United States consume by far the greatest amount of fish per person, 10.8 and 11.5 pounds, edible weight, respectively. Consumption averages considerably higher in the Caribbean countries—35.9 to 43.8 pounds for the Leeward and Virgin Islands, French West Indies, Barbados, and Bermuda. Consumption is relatively low in the South American countries, except for French and British Guiana, Surinam, and Venezuela, which range from 16.4 to 43.6 pounds.

In Europe most countries consume well over the world average. As might be expected, Iceland, Norway, and Sweden—54.7 to 67.9 pounds, fillet weight—top the list, followed by Denmark, the United Kingdom, and Portugal. Little reliable information is available for the African, Asiatic, and Oceanic countries, but consumption is reported relatively very high—74.0 to 106.7 pounds, including fresh and processed fish—in Siam, the Philippines, Japan, and Burma.*

The Food and Agriculture Organization has grouped the countries of the world in the following four categories, after attempting to convert all available data to an edible weight basis for a normal year (Anon., 1949):

(a) Very low consumption countries (less than 5 kg. or 11 lbs. per capita):
- Austria, Bulgaria, Czechoslovakia, Hungary, Ireland, Poland, Rumania, Switzerland, Yugoslavia.
- India, China, Java and Madura, Turkey.
- British Honduras, Costa Rica, Guatemala, Honduras, Mexico, Nicaragua, Panama, Salvador.
- Bahamas, Cuba, Dominican Republic, Haiti.
- Argentina, Bolivia, Brazil, Colombia, Ecuador, Paraguay, Peru, Uruguay.
- Algeria, Egypt, French Morocco, Kenya and Uganda, Madagascar, Tanganyika, Tunisia, Union of South Africa.

(b) Intermediate consumption countries (5.0–9.9 kg. or 11–21.8 lbs. per capita):
- Finland, France, Greece, Italy, Luxembourg.
- Australia, Ceylon, New Zealand.

* Anon., 1948; Anon., 1949; Frank, 1944; Sherr, Power, and Kahn, 1948 and 1949; Tousigant, 1948; Van Vliet and Snaith, 1949.

TABLE 32. ANNUAL PER CAPITA CONSUMPTION OF FISHERY PRODUCTS IN NORTH AND CENTRAL AMERICA.

Country	Year	Edible weight Pounds
British Honduras	1937–42	5.7
Canada [1]	1947	10.8
Costa Rica	1937–42	2.9
El Salvador	1937–42	0.4
Guatemala	1937–42	0.3
Honduras	1938–42	0.3
Mexico [2]	1946–47	[3] 5.0
Nicaragua	1937–42	0.2
Panama	1937–42	6.5
United States [4]	1935–39 [5]	11.1
	1948	11.5

[1, 2, 4] See *Source.*

[3] Weight basis not given—probably market weight.

[5] When indicating periods of time, a diagonal line is used for a 12-month period that differs from the calendar year; *e.g.* the fiscal year April 1 to March 31 is indicated as follows: 1940/1941. A dash (1940–1941) indicates a continuous period of years including both years specified. A calendar year is indicated by a single notation (1941).

Source: U. S. Bureau of Foreign and Domestic Commerce; except (1) Economics Division, Department of Fisheries, Canada; (2) Food and Agriculture Organization, and (4) U. S. Bureau of Agricultural Economics, U. S. Fish and Wildlife Service. (Anon., 1948; Anon., 1949; Frank, 1944; Sandberg, 1945a; Sherr, Power, and Kahn, 1948; Tousigant, 1948; Van Vliet and Smith, 1949.)

TABLE 33. ANNUAL PER CAPITA CONSUMPTION OF FISHERY PRODUCTS IN THE CARIBBEAN ISLANDS.

Country	Year	Edible weight Pounds
Bahamas	1937–41	7.1
Barbados	1937–41	38.4
Bermuda	1937–42	35.9
British West Indies	1937–42	30.2
Cuba	1937–42	8.3
Dominican Republic	1937–42	3.7
French West Indies	1937–41	39.0
Haiti	1937–42	2.6
Jamaica	1937–42	33.1
Leeward Islands	1937–41	43.8
Netherlands West Indies	1937–42	25.5
Puerto Rico	1937–42	25.6
Trinidad and Tobago	1937–41	27.6
Virgin Islands	1937–42	42.3
Windward Islands	1937–42	16.6

Source: Frank, U. S. Bureau of Foreign and Domestic Commerce (1944).

TABLE 34. ANNUAL PER CAPITA CONSUMPTION OF FISHERY PRODUCTS IN SOUTH AMERICA.

Country	Year	Edible weight Pounds
Argentina	1937–42	5.7
Bolivia	1937–41	1.0
Brazil	1937–41	2.5
British Guiana	1942	26.4
Chile	1940–42	7.9
Colombia	1942	.7
Ecuador	1942	1.5–2.0
French Guiana	1942	43.6
Paraguay	1937–40	0.2
Peru	1940–42	3.9
Surinam	—	21.4
Uruguay	1940–42	2.5
Venezuela	1938–41	16.4

Source: Frank, U. S. Bureau of Foreign and Domestic Commerce (1944).

TABLE 35. ANNUAL PER CAPITA CONSUMPTION OF FISHERY PRODUCTS IN EUROPE, 1947/1948.

Country	Fillet weight Pounds	Country	Fillet weight Pounds
Austria	4.4	Luxembourg	10.1
Belgium	22.5	Netherlands	[2] 22.9
Bulgaria	1.5	Norway	59.3
Czechoslovakia	5.7	Poland	[2] 6.4
Denmark	39.4	Portugal	28.2
Finland	15.7	Rumania	1.1
France	11.9	Spain	16.1
Germany:		Sweden	54.7
Bizone	13.9	Switzerland	4.4
French zone and Saar	6.6	U.S.S.R.:	
Soviet zone	2.2	Estonia [3]	[4] 59.7
Greece	17.0	Latvia [5]	[4] 42.8
Hungary	1.1	Lithuania [5]	[4] 22.5
Iceland [1]	67.9	United Kingdom	33.3
Ireland	8.2	Yugoslavia	1.3
Italy	[2] 12.1		

[1] 1946/1947.
[2] Fresh weight.
[3] 1937/1938.
[4] Per adult male—ILO data.
[5] 1936/1937.

Source: Food and Agriculture Organization (Anon., 1948; Anon., 1949).

TABLE 36. ANNUAL PER CAPITA CONSUMPTION OF FISHERY PRODUCTS IN AFRICA.

Country	Year	Weight [1] Pounds
Algeria	1947/48	6.2
Egypt	1947/48	6.6
French Morocco	1947/48	9.0
Gold Coast	—	19.4
Kenya and Uganda	1934–38	2.4
Madagascar	1947	9.9
Tanganyika	1946/47	2.4
Tunisia	1946/47	3.5
Union of South Africa	1947	5.7

[1] Basis not given.

Source: Food and Agriculture Organization (Anon., 1948; Anon., 1949).

TABLE 37. ANNUAL PER CAPITA CONSUMPTION OF FISHERY PRODUCTS IN ASIA AND OCEANIA, 1947–1948.

Country	Weight, includes fresh and processed Pounds
Australia	8.6
Burma	74.0
Ceylon	16.1
China	6.0
India/Pakistan	3.1
Indo-China	27.3
Japan	83.3
Java and Madura	7.7
Korea	[1] 39.7
Malaya	43.4
New Zealand	13.9
Philippines	101.4
Ryukyu Islands	[2] 97.0
Siam	106.7
Turkey	4.9

[1] Postwar, weight basis not given.
[2] Estimated, weight basis not given.

Source: Food and Agriculture Organization (Anon., 1948, Anon., 1949).

Canada, United States of America.
Windward Islands.
Chile, Surinam, Venezuela.
Gold Coast.

(c) High consumption countries (10.0–19.9 kg. or 22–44 lbs. per capita):
Belgium, Denmark, Germany, Netherlands, Portugal, Spain, United Kingdom.
Korea, Siam, Indo-China, Malaya.
Barbados, Bermuda, British West Indies, French West Indies, Jamaica (and in the Caymans), Leeward Islands, Netherlands West Indies, Puerto Rico, Virgin Islands.
British Guiana, French Guiana.

(d) Very high consumption countries (20.0 kg. — 44 lbs. — or more per capita):
Iceland, Norway, Sweden.
Burma, Japan, Philippines, Ryukyu Islands.

Fisheries of the United States

The catch of fish and shellfish in the United States and Alaska during 1948 reached an estimated 4.6 billion pounds, as compared with a 10-year average of 4.4 billion pounds and a peak catch of 5.08 billion pounds in 1941 (Table 38). The potential yield from our resources has been estimated at 7 billion pounds. (Power, 1945). During the 10-year period ending in 1948 the production per capita used for all purposes averaged about 32 pounds, while that portion used for human food averaged 22 pounds. The value of the 1948 catch to the fisher-

Table 38. Catch and Utilization of Fishery Products, United States and Alaska, 1939–1948.

(Round weight basis)

Year	Utilization				Total catch	
	Fresh and frozen	Canned	Cured	Byproducts and bait	Volume	Value
	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Thousand dollars
1939	1,366	1,281	130	1,666	4,443	96,532
1940	1,461	1,280	130	1,189	4,060	98,957
1941	1,660	1,645	125	1,650	5,080	134,172
1942	1,407	1,230	115	1,125	3,877	170,338
1943	1,495	1,165	114	1,428	4,202	204,029
1944	1,585	1,225	110	1,580	4,500	213,000
1945	1,846	1,230	110	1,389	4,575	269,900
1946	1,674	1,277	100	1,405	4,456	310,000
1947 [1]	1,569	1,384	100	1,315	4,368	302,000
1948 [1]	1,668	1,459	100	1,348	4,575	325,000
1939–48 10 yr. average [1]	1,573	1,318	113	1,410	4,414	212,393

[1] Preliminary data.

Source: U. S. Fish and Wildlife Service, (Anderson and Power, 1949; Anon., 1949e; Power, 1946).

men totaled an estimated $325,000,000, the highest in history, as compared with only $96,532,000 in 1939 and a 10-year average of about $212,393,000.

Direct employment was also at a peak in 1948 (Table 39). About 160,000 fishermen, aided by 4,000 transporters, landed the catch. In 4,000 plants on shore 110,000 workers processed, packed, and distributed fishery products. The fishing industry also accounted for the indirect employment of an estimated 300,000 persons in allied industries, such as gear manufacture, shipbuilding, manufacture of processing equipment, and service industries supplying food, fuel, etc.

About 85,000 craft, the largest and most effective fleet ever used, were engaged in the fisheries. They included 8,000 documented fishing vessels of 5 net tons or over, 40,000 motorboats, 35,000 other boats, 1,300 documented transporting vessels, and 700 transporting motorboats. From 1937 to 1944 less than 400 fishing craft were documented annually. A rapid increase, which amounted to 1,300 vessels in 1947, declined slightly to about 1,200 in 1948 (Table 40). Purse seines

TABLE 39. FISHING INDUSTRY OF THE UNITED STATES AND ALASKA IN CERTAIN YEARS.

	Unit	1931	1938	1945	1948 [1]
Catch:					
Volume	Pounds	2,657,000,000	4,253,445,000	4,575,500,000	4,575,000,000
Value	Dollars	77,344,000	93,547,000	269,900,000	325,000,000
Direct Employment:					
Fishermen	Number	122,775	130,184	141,919	160,000
Transporters	"	4,157	4,417	(2)	4,000
Shore workers	"	71,912	90,244	(2)	110,000
Fishing craft:					
Vessels	"	4,181	5,179	6,929	8,000
Motor boats	"	34,121	32,619	38,467	40,000
Other boats	"	38,361	39,495	35,041	35,000
Transporters:					
Vessels	"	1,275	1,375	(2)	1,300
Boats	"	1,229	974	(2)	700
Shore establishments	"	2,992	3,130	(2)	4,000

[1] Partly estimated. [2] Data not available.

Source: U. S. Fish and Wildlife Service (Anderson and Power, 1949; Anon., 1949e; Power, 1946).

TABLE 40. VESSELS OBTAINING THEIR FIRST DOCUMENTS AS FISHING CRAFT, UNITED STATES AND ALASKA, 1936–1948.*

Year	Number	Year	Number
1936	435	1942	358
1937	335	1943	358
1938	376	1944	635
1939	357	1945	741
1940	320	1946	1,085
1941	354	1947	1,300
		1948	1,200

* Partly estimated.

Source: U. S. Fish and Wildlife Service (Anderson and Power, 1949; Power, 1946).

TABLE 41. FISHERMEN, FISHING CRAFT, AND CATCH, UNITED STATES AND ALASKA, 1945, BY DISTRICTS.

District	Fishermen	Fishing craft			Catch					
		Vessels	Motorboats	Other boats	Fish		Shellfish, etc.		Total	
	Number	Number	Number	Number	Pounds	Value	Pounds	Value	Pounds	Value
New England	20,386	828	5,938	4,276	793,677,000	$40,649,000	51,794,000	$15,941,000	845,471,000	$56,590,000
Middle Atlantic	10,848	490	3,343	2,167	460,899,000	12,407,000	33,294,000	10,817,000	494,193,000	23,224,000
Chesapeake	17,673	299	7,447	5,865	229,092,000	14,490,000	75,371,000	15,873,000	304,463,000	30,363,000
South Atlantic and Gulf	29,697	1,735	7,999	8,686	476,888,000	19,871,000	269,139,000	34,459,000	746,027,000	54,330,000
Pacific	34,028	2,142	6,781	1,679	1,384,564,000	58,308,000	43,714,000	4,386,000	1,428,278,000	62,694,000
Lakes [1]	5,142	499	1,186	599	78,629,000	13,800,000	13,000	[2]	78,642,000	13,800,000
Mississippi River and tributaries [3]	15,884	—	4,426	10,120	44,062,000	5,211,000	38,321,000	1,400,000	82,383,000	6,611,000
Alaska	8,261	936	1,347	1,649	590,474,000	22,072,000	5,578,000	216,000	596,052,000	22,288,000
Total	141,919	6,929	38,467	35,041	4,058,285,000	186,808,000	517,224,000	83,092,000	4,575,509,000	269,900,000

[1] Employment data for 1940.
[2] Less than 500 dollars.
[3] Catch estimated; employment data for 1931.

Note: Persons employed as shore workers and transporters, and vessels and boats used as transporters are not included.
Source: U. S. Fish and Wildlife Service (Anderson and Power, 1949; Power, 1946).

usually account for about 45 per cent of the catch, otter trawls 20 per cent, all types of lines 9 per cent, pound nets 8 per cent, and gill nets 6 per cent (Walford, 1945).

In recent years the Pacific Coast States have been responsible for the greatest volume and the most valuable production, followed by the New England States, the South Atlantic and Gulf States, and Alaska (Table 41). California's production reached over 25 per cent of the total volume and 14 per cent of the total value in 1945. Alaska is usually second in production and Massachusetts third, with the positions reversed with respect to value (Sandberg, 1945).

San Pedro, California has been the nation's most important fishing port for some years (Table 42). Its landings of 460 million pounds in 1948 consisted

TABLE 42. LEADING PORTS, UNITED STATES AND ALASKA, 1948.

Port	Landings	
	Volume Pounds	Value Dollars
San Pedro, Calif.	460,000,000	30,000,000
Gloucester, Mass.	251,113,164	11,234,871
Beaufort and Morehead City, N. C.	210,000,000	3,000,000
San Diego, Calif.	200,000,000	35,000,000
Boston, Mass.	199,980,363	16,182,503
Reedville, Va.	153,000,000	1,600,000
Lewes, Del.	148,000,000	2,053,000
Monterey, Calif.	138,000,000	[1]
New Bedford, Mass.	77,571,522	11,772,568

[1] Complete data not available.

Source: U. S. Fish and Wildlife Service (Anderson and Power, 1949; Power, 1946).

primarily of tuna, pilchards, and mackerel for canning. Gloucester, Massachusetts was second with landings of 251 million pounds, mainly rosefish, ground fish, whiting and mackerel for the fresh and frozen fish trade. San Diego, California and Boston, Massachusetts received about 200 million pounds each, for canning and for the fresh and frozen market, respectively. In most years the little known ports of Lewes, Delaware; Reedville, Virginia; Beaufort and Morehead City, North Carolina; and Fernandina, Florida, rank high with huge landings of menhaden, caught almost wholly for reduction into fish meal and fish oil.

Since 1940 the largest part of the catch, from 33 to 40 per cent, has been marketed fresh or frozen (Tables 38, 43, and 44, and Figure 4). A definite trend toward frozen and packaged products led to the largest freezings in history—over 290 million pounds—in 1948. For the first time about half of the frozen products consisted of fillets. By-products and bait accounted for the second largest portion of the catch, from 29 to 35 per cent, closely followed by canned products, with 27 to 32 per cent. Cured products utilized the remainder, usually 2 to 3 per cent.

Seasonally, the greatest catches usually occur in the third quarter of the year; in a 1945 study they amounted to almost 43 per cent (Table 43). June to October, inclusive, were the highest producing months, with August the best by a small margin (Table 44). Frozen holdings in the nation's cold storage ware-

TABLE 43. QUARTERLY CATCH AND UTILIZATION OF FISH AND SHELLFISH, UNITED STATES AND ALASKA, 1945.
(Round Weight Basis)

Quarter	Fresh and frozen Per Cent	Canned Per Cent	Cured Per Cent	Byproducts Per Cent	Total Per Cent
1st	15.6	9.1	6.4	5.3	10.5
2nd	30.9	9.7	34.5	16.8	21.0
3rd	31.8	47.7	32.7	54.3	42.9
4th	21.7	33.5	26.4	23.6	25.6
Total	100.0	100.0	100.0	100.0	100.0

Source: U. S. Fish and Wildlife Service (Anderson and Power, 1949; Anon., 1949e; Power, 1946).

TABLE 44. MONTHLY CATCH AND UTILIZATION OF FISH AND SHELLFISH IN THE UNITED STATES AND ALASKA, 1945.
(Round Weight Basis)

Month	Marketed form: Fresh and Frozen 1,000 Pounds	Canned 1,000 Pounds	Cured 1,000 Pounds	Byproducts[1] and bait 1,000 Pounds	Total catch 1,000 Pounds	Total catch Per Cent
January	74,000	66,000	2,000	62,000	204,000	4.4
February	88,000	34,000	2,000	11,000	135,000	3.0
March	126,000	12,000	3,000	2,000	143,000	3.1
April	129,000	16,000	8,000	19,000	172,000	3.7
May	208,000	37,000	17,000	48,000	310,000	6.8
June	233,000	66,000	13,000	167,000	479,000	10.5
July	210,000	239,000	13,000	209,000	672,000	14.7
August	208,000	220,000	14,000	280,000	722,000	15.8
September	168,000	128,000	9,000	263,000	568,000	12.4
October	174,000	202,000	7,000	175,000	558,000	12.2
November	136,000	131,000	12,000	86,000	365,000	8.0
December	91,000	79,000	10,000	67,000	247,000	5.4
Total	1,846,000	1,230,000	110,000	1,389,000	4,575,000	100.0

[1] An additional 600 million pounds of waste from canning, dressing, and filleting operations was also used in the manufacture of by-products.

Note: Data partly estimated.

Source: U. S. Fish and Wildlife Service (Anderson and Power, 1949; Anon., 1949e; Power, 1946).

houses usually reach a peak in November, December, or January and a low point in April or May. The largest freezings occur in June, July, or August.

Twenty varieties of fish usually account for 90 per cent of the catch and over 80 per cent of its value (Table 45). From year to year the individual rankings shift.* In 1948 menhaden, salmon, pilchards, and tuna were the most productive

* Anderson and Power, 1949; Anon., 1949e; Power, 1946; Sandberg, 1945.

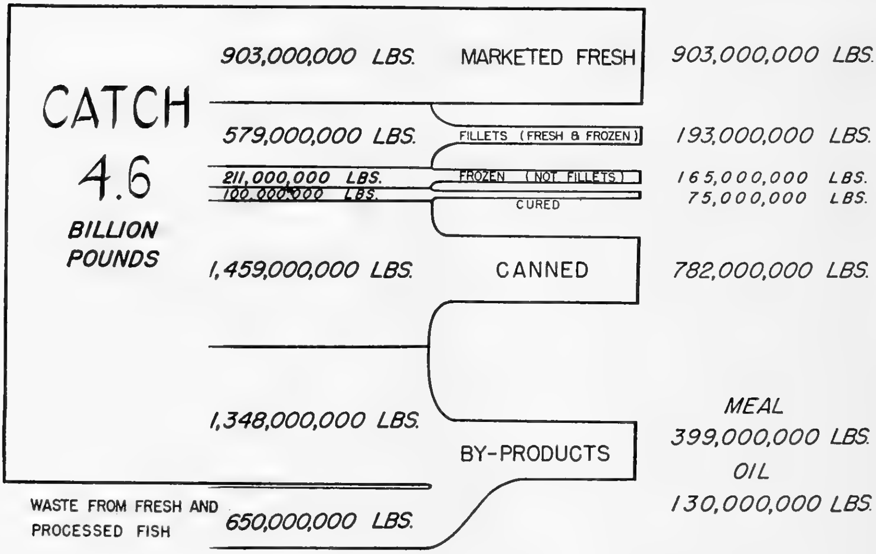
TABLE 45. RELATIVE VOLUME AND VALUE OF THE FISHERIES OF THE UNITED STATES AND ALASKA, 1945.
(Expressed in thousands of pounds and thousands of dollars.)

Catch by fishermen					Returns to fishermen				
Position	Species	Volume (000 lbs.)	Per Cent of Total: U. S. and Alaska	Per Cent of Total: Cumulative	Position	Species	Value (000 dollars)	Per Cent of Total: U. S. and Alaska	Per Cent of Total: Cumulative
1.	Pilchard	849,971	18.6	18.6	1.	Salmon	25,692	9.7	9.7
2.	Menhaden	778,464	17.0	35.6	2.	Oysters	25,147	9.5	19.2
3.	Salmon	498,892	10.9	46.5	3.	Tuna	21,913	8.2	27.4
4.	Sea herring	236,919	5.2	51.7	4.	Shrimp	21,369	8.0	35.4
5.	Shrimp	191,345	4.2	55.9	5.	Haddock	10,828	4.1	39.5
6.	Tuna	185,925	4.1	60.0	6.	Pilchard	9,462	3.6	43.1
7.	Haddock	154,988	3.4	63.4	7.	Lobsters, northern	9,460	3.6	46.7
8.	Cod	153,027	3.3	66.7	8.	Crabs	9,383	3.5	50.2
9.	Rosefish	131,834	2.9	69.6	9.	Cod	9,274	3.5	53.7
10.	Crabs	121,050	2.6	72.2	10.	Clams	9,079	3.4	57.1
11.	Mackerel	112,390	2.5	74.7	11.	Flounders	8,648	3.2	60.3
12.	Flounders	108,071	2.4	77.1	12.	Croakers	6,950	2.6	62.9
13.	Whiting	90,029	2.0	79.1	13.	Halibut	6,850	2.6	65.5
14.	Oysters	75,655	1.6	80.7	14.	Mackerel	6,242	2.3	67.8
15.	Croakers	64,668	1.4	82.1	15.	Sea trout	6,110	2.3	70.1
16.	Rockfishes	57,686	1.3	83.4	16.	Menhaden	6,061	2.3	72.4
17.	Halibut	51,380	1.1	84.5	17.	Rosefish	5,066	1.9	74.3
18.	Sea trout	50,835	1.1	85.6	18.	Mullet	4,647	1.7	76.0
19.	Mullet	42,767	.9	86.5	19.	Lake trout	4,056	1.5	77.5
20.	Pollock	37,633	.8	87.3	20.	Sharks	3,938	1.5	79.0
	All other	581,980	12.7	100.0		All other	56,011	21.0	100.0
	Total	4,575,509	100.0	100.0		Total	266,186	100.0	100.0

Source: Anderson and Power, U. S. Fish and Wildlife Service (1949).

fisheries, while fishermen received the greatest income from their catches of salmon, tuna, oysters, and shrimp. Salt-water fin-fish usually make up about 85 per cent of the catch, salt-water shellfish about 10 per cent, and fresh-water fish the remaining 5 per cent.

In 1948 menhaden ranked highest in volume. A record catch of over 1 billion pounds was taken from Atlantic and Gulf Coast waters. The catch represents over one-third of the total production of the area and is utilized almost exclusively



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 12–4. Flow chart of the commercial fisheries of the United States and Alaska, 1948.

to manufacture livestock and poultry feeds, feeding oils, and industrial oils for use in paint, soap, and the technical processing of various products.

The five species of Pacific salmon—chinook or king, red or sockeye, silver or coho, pink, and chum—are the bulwark of Alaska's fisheries and are of considerable but varying importance in each of the Pacific Coast States. They constitute one of the most valuable fisheries in the world, furnishing the raw material for the world's largest pack of canned fish. In 1948 the estimated catch was 400 million pounds, well below the record total of 791 million pounds in 1936.

Until 1946 the Pacific Coast pilchard fishery was surpassed only by the great herring and ground fish fisheries of Europe. The peak production of 1.5 billion pounds in 1936 dropped to 850 million pounds in 1945, 531 million pounds in 1946, and 272 million pounds in 1947 before recovering to 373 million pounds in 1948. Intensive research is being undertaken to determine the cause of the decline. The catch is utilized for canning and for reduction into fish meal and fish oil, the emphasis varying with the demand and profit. The greatest canned pack was over 5 million cases in 1941, while 122 thousand tons of meal and over 26 million gallons of oil were produced in 1936.

The Pacific Coast tuna fishing area extends from Ecuador to Alaska, with an

outpost in Hawaii and operations beginning in waters farther west. Spectacular increases in catches of tuna and tunalike fishes—yellowfin, albacore, bluefin, skipjack, bonito, and yellowtail—have resulted in a series of record volumes of raw fish and the canned product. In 1948 all previous totals were surpassed by a catch of 326 million pounds from which 7 million cases of canned tuna were produced.

Sea herring are caught chiefly in Maine and Alaska, the combined catch in 1948 amounting to 348 million pounds as compared with the previous record of 310 million pounds in 1947. In Maine the bulk of the catch is canned, 182 million pounds in 1948, along with nearly 58 million pounds of imported herring from Canada, producing a record pack of about 3.3 million cases. Alaska herring, 166 million pounds in 1948, is processed into fish meal and oil, except for small quantities that are salted or used as bait.

Ground fish—cod, haddock, hake, pollock, and cusk—supported the New England fishing industry for years. Cod was taken in the greatest volume until the advent of filleting in the early twenties increased the demand for haddock. The largest recorded catches of cod were 295 million pounds in 1880, of haddock, 265 million pounds in 1930. In 1948 the combined domestic catches of cod, haddock, hake, pollock, and cusk on the Atlantic Coast totaled 300 million pounds, of which haddock made up 160 million pounds and cod 73 million pounds. Ground fish are used chiefly in the fresh or frozen market. The amount canned and cured is small, the once great volume of salt fish having long since been superseded by foreign production and imported raw material.

Landings of rosefish in New England were only 74 thousand pounds in 1929. In 1948 the largest catch in its brief history, 238 million pounds, was greater than that of any other Atlantic Coast species, except menhaden, and it formed the basis for a flourishing trade in fresh and frozen packaged fillets.

The mackerel fisheries of California utilize the Pacific mackerel and the "jack" mackerel—a member of the jack family—to produce large canned packs. The combined catch of 109 million pounds in 1948 yielded over 1 million cases. The largest catch ever taken was 173 million pounds in 1947 and the greatest pack, 1.5 million cases in the same year. The Atlantic Coast mackerel fishery, carried on from Norfolk, Virginia, north, provides an important fresh and frozen fish product and some canned fish. The 1948 catch of about 45 million pounds was far below the pre-1900 production and the record catch of 179 million pounds in 1884.

The most important shellfish fishery, both in volume and value, is that for shrimp in the South Atlantic and Gulf States. In recent years the number of fishing craft has increased rapidly until it was estimated that about 4,500 trawlers took 175 million pounds of shrimp in 1948. Shrimp are canned, dried, frozen, cooked, and sold fresh, but the trend is toward frozen fresh and frozen cooked products.

The oyster fishery is of some importance in every seaboard state, except Maine and New Hampshire, and in 1945 was the nation's second most valuable fishery. It is dependent on the eastern oyster, found on the Atlantic and Gulf Coasts, and on the western, or native, and the Pacific oyster, introduced from Japan, which is cultivated on the Pacific Coast. The Atlantic and Gulf Coast production totaled 65.4 million pounds of oyster meats in 1948. Most of the yield was marketed fresh in the shell or shucked, frozen shucked, or canned. Pacific Coast production in

the same year amounted to 10.1 million pounds of Pacific oyster meats, which were sold fresh and canned, and 151 thousand pounds of native oyster meats which were marketed fresh.

The crab fishery is based chiefly on the blue crab found on the Atlantic and Gulf Coasts, the Dungeness crab of the Pacific Coast, and the king crabs of Alaska, which have been sought by U. S. fishermen only since 1940. The blue crab catch in 1945 was 102 million pounds, most of which was marketed as fresh picked meat. Dungeness crab production of 17 million pounds was marketed as cooked meat, canned, and cooked in the shell. King crab production is very small, though increasing. Marketing forms include frozen picked meat, frozen cooked in the shell, and canned.

Fish meal and oil, condensed fish solubles, liver and viscera oils, glue, pearl essence, marine plant products, such as agar, Irish moss, alginates, etc., and shell products represent the more important items generally classified as by-products of the United States fishing industry. In 1948 there were 298 plants involved in the manufacture of by-products (Anon., 1949e).

Fish meal, a negligible amount of scrap, and fish body oils are produced from whole menhaden, herring, and pilchards, as well as from the processing waste from pilchards, "ground fish" (cod and related species), rosefish, tuna and mackerel, Maine sardines, and a number of less important sources, such as salmon, blue crab, shrimp, etc. In 1948 199,519 tons of fish meal and scrap, valued at

TABLE 46. PRODUCTION OF MARINE-ANIMAL SCRAP AND MEAL, UNITED STATES AND ALASKA, 1948.

Product	Atlantic and Gulf Coasts		Pacific Coast (Including Alaska) [1]		Total	
	Tons	Value	Tons	Value	Tons	Value
Meal and Dried Scrap:						
Anchovy	—	—	163	$21,517	163	$21,517
Crab, Blue	5,151	$266,761	—	—	5,151	266,761
Fur Seal	—	—	341	36,996	341	36,996
Ground Fish ("White Fish") including Rosefish	21,780	2,872,544	—	—	21,780	2,872,544
Herring	4,632	431,221	13,054	1,633,821	17,686	2,065,042
Menhaden	[2] 104,058	11,560,914	—	—	104,058	11,560,914
Pilchard	—	—	19,076	2,614,616	19,076	2,614,616
Salmon	—	—	1,152	112,223	1,152	112,223
Shark	[3]	[3]	[4] 106	[4] 11,178	106	11,178
Shrimp	724	49,016	—	—	724	49,016
Tuna and Mackerel	—	—	21,305	2,757,778	21,305	2,757,778
Whale:						
Meat	10	700	409	40,900	419	41,600
Bone	—	—	60	3,000	60	3,000
Miscellaneous	[5] 3,124	319,591	[6] 4,374	353,958	7,498	673,549
Total	139,479	15,500,747	60,040	7,585,987	199,519	23,086,734

[1] Includes small production of unclassified meal in Minnesota and shark meal in Florida.

[2] A small production of acidulated scrap has been included with dry scrap and meal.

[3] Included with West Coast production.

[4] Includes Florida production.

[5] Includes the production of cod-liver press cake, fish pomace, and alewife, horseshoe crab, lobster, and miscellaneous fish scrap and meal.

[6] Includes a small production of unclassified meal in Minnesota, Dungeness crab and miscellaneous scrap and meal on the Pacific Coast.

Source: Anon., U. S. Fish and Wildlife Service (1949e).

TABLE 47. PRODUCTION OF MARINE-ANIMAL OIL, UNITED STATES AND ALASKA, 1948.

Product	Atlantic and Gulf Coasts [1]		Pacific Coast (Including Alaska)		Total	
	Gallons	Value	Gallons	Value	Gallons	Value
From Body and Waste:						
Anchovy	—	—	15,407	$15,320	15,407	$15,320
Fur Seal	—	—	47,711	42,484	47,711	42,484
Herring	102,270	$86,077	3,541,267	3,918,173	3,643,537	4,004,250
Menhaden	8,763,939	10,132,179	—	—	8,763,939	10,132,179
Pilchard	—	—	2,328,572	2,457,858	2,328,572	2,457,858
Salmon:						
Edible	—	—	22,065	77,228	22,065	77,228
Industrial	—	—	94,264	93,150	94,264	93,150
Tuna and Mackerel	—	—	660,515	622,110	660,515	622,110
Whale:						
Sperm	—	—	62,332	66,071	62,332	66,071
Other	2,650	2,427	55,107	61,719	57,757	64,146
Miscellaneous [2]	517,493	756,963	129,815	144,096	647,308	901,059
Total	9,386,352	10,977,646	6,957,055	7,498,209	16,343,407	18,475,855
From Livers and Viscera:						
Cod	214,127	583,426	—	—	214,127	583,426
Shark	(3)	(3)	434,010 [3]	6,315,232 [3]	434,010	6,315,232
Tuna	(3)	(3)	25,459 [3]	1,094,241 [3]	25,459	1,094,241
Miscellaneous [4]	1,995	111,286	64,546	4,403,467	66,541	4,514,753
Total	216,122	694,712	524,015	11,812,940	740,137	12,507,652
Grand Total	9,602,474	11,672,358	7,481,070	19,311,149	17,083,544	30,983,507

[1] Includes a small production of burbot liver oil and unclassified body oils in Minnesota.

[2] Includes the production of alewife, blackfish, rosefish, and unclassified body oils on the east coast and unclassified body oils on the west coast.

[3] East and west coast production combined.

[4] Includes the production of burbot, halibut, rockfish, and swordfish liver oils on the east coast and halibut, lingcod, sablefish, mixed liver oils, and viscera oils on the west coast.

Source: Anon., U. S. Fish and Wildlife Service (1949e).

$23,087,000, and 16,343,000 gallons of body oils, valued at $18,476,000, were produced. Liver and viscera oils, potent sources of vitamins, are derived mainly from sharks, tuna, cod, halibut, lingcod, sablefish, and rockfish. The 1948 production amounted to 740,137 gallons, valued at $12,507,652 (Tables 46 and 47). Glue, condensed fish solubles—an evaporated product derived from the "stickwater" formerly discarded in the wet process of producing meal and oil—pearl essence, and marine plant products, etc., manufactured in 1948, were valued at $9,285,458 (Table 48). From oyster and marine clam shells were manufactured 345,075 tons of crushed shell for poultry feed and unburned shell lime, valued at $2,474,000 (Table 49). Fresh-water mussel shell products—buttons, crushed-shell poultry feed, lime, and chips, shells, and novelties—were valued at $5,447,000 (Table 50). Marine pearl-shell buttons numbered 4,974,073 gross, valued at $8,587,000 (Table 51).

During the period from 1930 to 1948 the per capita consumption of fishery products in the United States on an edible weight basis varied from a low of 8.2 in 1943 to a high of 12.0 pounds in 1936 (Table 52). Consumption during the three war years, 1942–1944, ranged from 8.2 to 8.9 pounds, and in four depression years, 1931–1934, from 8.9 to 9.5 pounds. All other years were 10.5 pounds or higher. Per capita consumption in 1948 amounted to about 11.5 pounds.

TABLE 48. PRODUCTION OF MISCELLANEOUS BYPRODUCTS, UNITED STATES AND ALASKA, 1948.

Product	Unit	Quantity	Value	Location and Number of Plants
Glue	Gallons	215,400	$502,041	Maine 1, Massachusetts 3, California 1
Fish Solubles	Pounds	32,117,494	1,471,723	Massachusetts 3, Mississippi 1, Oregon 1, California 7
Miscellaneous [1]	—	—	7,311,694	Maine 6, Massachusetts 3, North Carolina 2, South Carolina 1, California 5
Total	—	—	$9,285,458	

[1] Includes the production of agar-agar, kelp products, pearl essence, isinglass, Irish moss, fish chum (bait), homogenized condensed fish, and crab shells.

Source: Anon., U. S. Fish and Wildlife Service (1949e).

TABLE 49. PRODUCTION OF OYSTER AND MARINE CLAM-SHELL PRODUCTS, UNITED STATES AND ALASKA, 1948.[1]

State	Crushed Shell for Poultry Feed		Unburned Shell Lime		Total	
	Tons	Value	Tons	Value	Tons	Value
New Jersey	5,344	$77,546	1,319	$6,424	6,663	$83,970
Pennsylvania and Maryland	26,766	263,141	17,308	73,518	44,074	336,659
Virginia, Florida, Louisiana, and Texas	242,874	1,592,047	[2] 25,472	224,064	268,346	1,816,111
Washington, Oregon, and California	21,586	207,971	4,406	29,781	25,992	237,752
Total	296,570	2,140,705	48,505	333,787	345,075	2,474,492

[1] Marine clam-shell products were produced in 1 plant in Washington.
[2] Includes a small quantity of burned lime produced in Virginia.

Note: Crushed shell products were prepared in 5 plants in New Jersey, 4 plants each in Pennsylvania and Washington, 3 plants in Virginia, 2 plants each in Maryland, Texas, and California, and 1 plant each in Florida, Louisiana, and Oregon.
Source: Anon., U. S. Fish and Wildlife Service (1939e).

TABLE 50. PRODUCTION OF FRESH-WATER MUSSEL-SHELL PRODUCTS, UNITED STATES AND ALASKA, 1948.

Product	Unit	Iowa and Missouri		New York, Pennsylvania and Illinois		Total	
		Quantity	Value	Quantity	Value	Quantity	Value
Buttons	Gross	5,688,904	$4,261,195	1,121,231	$1,135,316	6,810,135	$5,396,511
Crushed-Shell Poultry Feed	Tons	[1] 852	[1] 8,522	(1)	(1)	852	8,522
Lime	Tons	1,368	3,678	—	—	1,368	3,678
Chips, Shells, and Novelties	—	—	38,410	—	—	—	38,410
Total	—	—	4,311,805	—	1,135,316	—	5,447,121

[1] A small production in New York has been included with that in Iowa and Missouri.

Note: Mussel shells purchased during the year amounted to 9,657 tons, valued at $452,343. Shells were taken in 13 states in the Mississippi River and Great Lakes Region. The producing states in the order of their importance were: Tennessee, which contributed 40 per cent of the total quantity; Kentucky, 23 per cent; Alabama, 19 per cent; Indiana, 8 per cent; Arkansas, 5 per cent; Illinois, 4 per cent; and Iowa, Michigan, Minnesota, Missouri, Ohio, South Dakota, and Texas, 1 per cent.
Source: Anon., U. S. Fish and Wildlife Service (1949e).

TABLE 51. PRODUCTION OF MARINE PEARL-SHELL BUTTONS, UNITED STATES AND ALASKA, 1948.[1]

State	Gross	Value
New York	1,358,712	$2,248,887
New Jersey	1,333,384	2,198,112
Connecticut	1,055,467	1,914,499
Pennsylvania, Maryland, and Iowa	1,226,510	2,225,513
Total	4,974,073	8,587,011

[1] Produced principally from imported shells.

Note: Marine pearl-shell buttons were manufactured in 4 plants in New York, 12 in New Jersey, 3 in Connecticut, 2 in Pennsylvania, 1 in Maryland, and 2 in Iowa.

Source: Anon., U. S. Fish and Wildlife Service (1949e).

TABLE 52. CIVILIAN PER CAPITA CONSUMPTION OF FISHERY PRODUCTS IN THE CONTINENTAL UNITED STATES, 1930–1948.

Year	Fresh and Frozen Pounds	Canned Pounds	Cured Pounds	Total Fresh and Processed Pounds
1930	5.9	3.3	1.3	10.5
1931	5.0	3.2	1.0	9.2
1932	4.4	3.4	1.1	8.9
1933	4.2	3.9	.9	9.0
1934	4.4	4.2	.9	9.5
1935	5.2	4.7	1.1	11.0
1936	5.2	5.8	1.0	12.0
1937	5.6	4.2	.9	10.7
1938	5.3	4.8	1.0	11.1
1939	5.4	4.6	.9	10.9
1935–39 average	5.3	4.8	1.0	11.1
1940	5.7	4.2	.9	10.8
1941	6.3	4.7	.8	11.8
1942	5.3	2.2	.8	8.3
1943	5.6	1.9	.7	8.2
1944	5.6	2.6	.7	8.9
1945	7.1	2.6	.9	10.6
1946	6.3	3.8	1.0	11.1
1947	6.2	3.8	.8	10.8
1948 (estimated)	6.7	4.0	.8	11.5

Source: U. S. Bureau of Agricultural Economics and U. S. Fish and Wildlife Service (Sherr, Power, and Kahn, 1948 and 1949).

In post war years fresh and frozen products have accounted for about 57 per cent of the average consumption of 11.1 pounds, canned products about 35 per cent, and cured products about 8 per cent as compared with 1935–1939 averages of 48 per cent, 43 per cent, and 9 per cent, respectively (Sherr, Power, and Kahn, 1948 and 1949).

In 1939 the Bureau of Labor Statistics index number for the average monthly retail price for fresh and frozen fish was 99.8 as compared with a 1935–1939 average of 100 (Table 53). In 1948 the index number was 264.9. The average price of red salmon rose from 23.6 cents per 1-pound can in 1939 to an estimated 69 cents in 1948 and pink salmon from 13.1 cents to 54.9 cents.

TABLE 53. INDEX NUMBERS OF AVERAGE MONTHLY RETAIL PRICES OF SPECIFIED FOODS IN LEADING CITIES AND AVERAGE MONTHLY RETAIL PRICE FOR CANNED SALMON IN THE UNITED STATES, 1939–1948.
(1935–1939 average = 100)

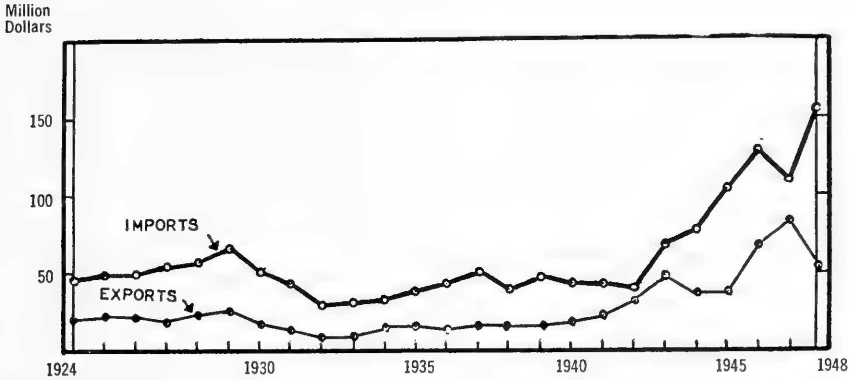
Year	Fresh and Frozen Fish Index No.	Red Salmon ¢ per lb.	Pink Salmon ¢ per lb.	Meats Index No.	Dairy Products Index No.	Eggs Index No.
1939	99.8	23.6	13.1	96.6	95.9	91.0
1940	106.7	25.7	15.6	94.4	101.4	93.8
1941	119.2	30.4	17.9	106.5	112.0	112.2
1942	160.0	39.8	21.6	122.5	125.4	136.5
1943	209.0	41.3	23.5	124.2	134.6	161.9
1944	209.6	42.0	23.5	117.9	133.6	153.0
1945	220.4	40.4	23.3	118.0	133.9	164.4
1946	240.6	[1] 44.0	[1] 25.3	150.8	165.1	168.8
1947	243.4	[2] 60.4	42.4	214.7	186.2	200.8
1948	264.9	[3] 69.0	55.0	243.9	204.8	208.7

[1] 11 month average price.
[2] Average for first 6 months.
[3] Estimated by U. S. Fish and Wildlife Service.
Note: 51 cities covered prior to February 1943, 56 cities thereafter.
Source: U. S. Bureau of Labor Statistics.

U. S. Foreign Trade in Fish and Fishery Products

During the pre-war period, 1935–1939, the foreign trade in fish and fishery products of the United States averaged 57 million dollars annually (Table 54). Imports accounted for 75 per cent and exports for the remaining 25 per cent. By 1948 imports and exports had increased in value to a total of $210,127,484, the percentage relationships remaining practically unaltered (Lund, 1946; Sallee and Wallar, 1949). However, within the export category there was a striking rise in the value of inedible products, the result of increased trade in fish and marine animal oils, mostly vitamin-bearing. The major edible fishery products imported in 1948 were: ground fish fillets, 53,963,546 pounds, valued at $10,751,-838; canned sardines, 31,155,954 pounds, valued at $10,737,400; and pickled or salted ground fish, 54,887,465 pounds, valued at $8,643,343.

The more important inedible products included: fish and marine animal oils, 10,808,856 gallons, valued at $23,118,305; fish scrap and meal, 41,124 tons,



(Courtesy U. S. Fish and Wildlife Service)

FIG. 12–5. United States imports and exports of fishery products, 1924–1948.

TABLE 54. UNITED STATES FOREIGN TRADE IN FISHERY PRODUCTS, 1935–1939 AND 1948.

Item	5-year Average 1935–1939		1948	
	Pounds	Value	Pounds	Value
Imports:				
Edible	341,893,894	$30,510,972	473,227,979	$111,598,487
Inedible	—	12,298,215	—	44,892,064
Total	—	42,809,187	—	156,490,551
Exports:				
Edible	118,603,501	13,249,242	99,712,081	22,844,111
Inedible	—	906,349	—	30,792,822
Total	—	14,155,591	—	53,636,933
Foreign trade:				
Total	—	56,964,778	—	210,127,484

Source: U. S. Bureau of the Census (Lund, 1946; Sallee and Wallar, 1949).

valued at $5,056,856; and shells and buttons, valued at $3,704,860. Inedible exports consisted mainly of fish and marine animal oils, 19,714,551 pounds, valued at $29,316,985. Edible exports were chiefly canned sardines including pilchards, 33,877,002 pounds, valued at $8,153,182; other canned fish, 41,808,427 pounds, valued at $9,765,473; and canned shellfish, 15,679,936 pounds, valued at $2,583,004.

Imports have been stimulated by expanded fisheries in foreign countries and their need for dollar exchange. Exports have diminished because of the dollar shortage in former foreign markets and competition from newly developed or expanded production in soft currency countries.

Of the imports of fishery products in 1948 only those listed in Table 54A (p. 230) entered the U. S. free of duty.

From 1936 to 1940 the average duty collected on fish and fishery products amounted to $6,257,386.

TABLE 54A. *Edible Fishery Products Entered Free of Duty, 1948*

Fresh and frozen:		
Sea herring	Crabs	Scallops
Smelt	Lobsters	Shrimp
Tuna	Oysters	Turtles (live)
Clams		
Canned:		
Abalone	Lobster meat	Lobster paste and sauce

Under accepted principles of evaluation the commercial fishery resources of the United States were worth $11,323,645,000 in 1948 (Table 55). If there were no fishery resources, the nation would have had to invest this amount at 4 per cent interest in order to maintain the earnings of the fishery industries in 1948, a record year.

TABLE 55. CAPITALIZED VALUE OF THE COMMERCIAL FISHERY RESOURCES OF THE UNITED STATES, 1948.

Item	Value *
Value to:	
Fishermen and boat owners	$6,093,750,000
Manufacturers and processors	1,504,995,000
Wholesalers of fishery products	1,731,674,000
Retailers of fishery products	1,993,226,000
Total	11,323,645,000

* If the nation had no fishery resources this amount would have to be invested at 4 per cent to maintain the 1948 earnings of the members of the fishery industries.

Source: U. S. Fish and Wildlife Service.

When purchased by the consumer the products of the industry were worth an estimated $996,613,000 in 1948. The data for earlier years, and for the ex-vessel, processing, and wholesale levels are shown in Table 56. In 1948 the estimated replacement value of fishing craft, gear, processing plants, wholesale establishments, etc. was $951,000,000 (Table 57). The U. S. Fish and Wildlife Service estimated

TABLE 56. VALUE OF FISHERY PRODUCTS AT VARIOUS LEVELS OF PRODUCTION AND DISTRIBUTION IN THE UNITED STATES AND ALASKA, 1939–1948.

	Production or Distribution Level			
Year	Ex-vessel	Processor	Wholesale	Retail
1939	$ 96,532,000	$188,237,000	$245,480,000	$316,431,000
1940	99,000,000	198,200,000	255,600,000	327,400,000
1941	134,172,000	261,635,000	341,199,000	439,815,000
1942	170,338,000	332,159,000	433,169,000	558,367,000
1943	204,000,000	397,759,000	518,711,000	668,692,000
1944	213,000,000	415,307,000	541,595,000	698,193,000
1945	269,900,000	526,251,000	686,275,000	884,705,000
1946	287,700,000	560,957,000	731,535,000	943,052,000
1947	302,000,000	585,330,000	767,895,000	989,926,000
1948	325,000,000	601,998,000	769,633,000	996,613,000

Source: U. S. Fish and Wildlife Service.

TABLE 57. ESTIMATE OF CAPITAL INVESTMENT IN COMMERCIAL FISHERIES OF THE UNITED STATES AND ALASKA.

Item	1948 Replacement Value
Producers:	
Vessels and boats	$358,500,000
Nets and other gear	59,900,000
Freezing and processing plants	231,100,000
Wholesale fish houses *	207,300,000
Retail fish dealers, chain stores, etc.*	94,200,000
Total	$951,000,000

* Capital investment devoted to fish trade.

Source: U. S. Fish and Wildlife Service.

that annually producers turn over their capital investments devoted to fishery interests once, wholesalers and processors about 4.4 times and retailers about 15 times.

Profits in the fishing industry are subject to many variations. A study for the year, completed in 1945, indicated there was an average profit of 9 per cent of sales to the vessel owner, 5 per cent to the wholesaler, and 3 per cent to the retailer (Walford, 1945) (Table 58). In 1948 changed conditions indicated that because of higher prices and a higher sales volume the percentages of profit related to sales may have been reduced slightly.

In 1940 the U. S. Fish and Wildlife Service calculated that the average fisherman produced 47,000 pounds of food as compared to 34,500 pounds produced by

TABLE 58. DISPOSITION OF AVERAGE DOLLAR RECEIVED BY VESSEL OWNER, WHOLESALER AND RETAILER, 1945.

Item	Vessel Owner Per Cent	Wholesaler Per Cent	Retailer Per Cent
Boat supplies, repairs, and depreciation	16	—	—
Fishing gear	5	—	—
Ice and storage	2	—	1
Fuel and oil	5	—	—
Food	3	—	—
Fishermen's share and labor	53	—	—
Vessel owner for fish	—	70	—
Wholesaler for fish	—	—	65
Wages and salaries	—	12	18
Rent	—	1	4
Packaging and wrapping supplies, etc.	—	2	3
Delivery expenses	—	3	1
Miscellaneous	7	7	5
Profit	9	5	3
Total	100	100	100

Source: Walford, U. S. Fish and Wildlife Service (1945).

the average farmer. In 1947, when production averages were believed similar, the fisherman paid approximately $541.38 in Federal taxes, the farmer $177.17. In return the Federal government made a direct expenditure of $21.07 for each fisherman during its 1948 fiscal year or about 90 cents per ton of fishery products as compared with a direct expenditure of $98.88 for each farmer and $5.73 for each ton of farm products. Expenditures for agriculture were for research, informational services, and subsidies; for the fishing industry only the first two since there were no fishery subsidies.

REFERENCES

Allen, Edward W., "The Halibut Commission—Its Legal Powers and Function," *International Fisheries Commission Circ.*, **1** (1936).

Anderson, A. W., "The Indo-Pacific Fisheries Council," *Department of State Bull.*, **19**, No. 470, Publication No. 3207, 12 (1948).

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

Anon., "Report of the International Pacific Salmon Fisheries Commission for the Years 1937 and 1938," New Westminster, B. C., Canada, International Pacific Salmon Fisheries Commission, *Annual Report 1937 and 1938*, 1939.

Anon., "Fisheries," United Nations Interim Commission on Food and Agriculture, *Report of the Technical Committee on Fisheries* (1945).

Anon., "Report of the Third Session of the Conference," Food and Agriculture Organization, p. 11 (1947).

Anon., "The State of Food and Agriculture, 1948," 4th Session, Food and Agriculture Organization, C48/8, 48, 69, 88, 101 and 129 (1948).

Anon., "Yearbook of Fisheries Statistics—1947," Fisheries Division, Food and Agriculture Organization (1948a).

Anon., "Computing Human Consumption of Fish," Fisheries Division, Food and Agriculture Organization, *Fisheries Bulletin*, **2**, No. 2, 2 (1949).

Anon., General Headquarters Supreme Commander for the Allied Powers, Tokyo, Japan, *Natural Resources Section Weekly Summary*, **213**, 20 (November 6–12, 1949a).

Anon., "Proposed General Fisheries Council for the Mediterranean," 5th Session, Food and Agriculture Organization, C49/14 (October 17, 1949b).

Anon., "Summary of Landings and Principal End-Products in Certain Countries," Fisheries Division, Food and Agriculture Organization, *Fisheries Bulletin*, **2**, No. 3, Tables 29 and 30 (1949c).

Anon., "The Fisheries Conventions," Hearing Before a Subcommittee of the Committee on Foreign Relations, U. S. Senate, 81st Congress, 1st Session (July 14, 1949d).

Anon., "Canned Fish and Byproducts—1948." U. S. Fish and Wildlife Service, *Annual Summary, 1948*, C.F.S. No. 497 (1949e).

Day, A. M., "Old Man of the Pribilofs," *Scientific Monthly*, **68**, 329 (1949).

Fiedler, R. H., and Frank, M., "Fishery Statistics," United Nations Interim Commission on Food and Agriculture, *Subcommittee on Statistics Doc.*, **7** (1944).

Frank, M., "Fisheries of Latin America," U. S. Bureau of Foreign and Domestic Commerce, Reprint from *Foreign Commerce Weekly* (Mar., Oct., Nov., Dec., 1944).

Lund, E. E., "United States Foreign Trade in Fish and Fish Products." Office of International Trade, *Industrial Reference Service*, **4**, Part 5, No. 27 (1946).

Power, E. A., "What Are the Limits of Our Fishery Resources and to What Extent Will Increased Fish Consumption Approach These Limits?" Address Before Post-War Resources Institute, U. S. Dept. of the Interior (Nov., 1945).

Power, E. A., "Fishery Statistics," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **8,** No. 3, 1 (1946).

Sallee, G. A., and Wallar, M. W., "United States Foreign Trade in Fish and Fish Products." Office of International Trade, *World Trade in Commodities,* **7,** Parts 6, 7, and 8, No. 14 (1949).

Sandberg, A. M., "The Relative Productivity and Value of the Fisheries of the United States and Alaska," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **108** (1945).

Sandberg, A. M., "The Fisheries of the World," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **109** (1945a).

Sherr, H., Power, E. A., and Kahn, R. A., "Supply and Distribution of Fishery Products in the Continental United States," U. S. Bureau of Agricultural Economics, *The National Food Situation,* NFS–45 (1948).

Sherr, H., Power, E. A., and Kahn, R. A., "United States per Capita Consumption of Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **10,** No. 11, 1 (1948). Also, *Fishery Leaflet,* **352** (1949).

Tousignant, J. B., "Fish Consumption in Canada," Economics Division, Canadian Department of Fisheries (1948).

Truman, Harry S., "Policy of the United States with Respect to Coastal Fisheries in Certain Areas of the High Seas," U. S. Department of State (Sept. 28, 1945).

Van Vliet, W., and Snaith, W. E., "Regional Consumption of Fish in Canada," Economics Division, Canadian Department of Fisheries (1949).

Walford, L. A., "Fishery Resources of the United States of America," U. S. Fish and Wildlife Service (1945). Also, "Fishery Resources of the United States," *Doc.,* **51,** 79th Congress, 1st Session, U. S. Senate (1945).

CHAPTER 13

Fishing Gear and Fishery Methods

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Early Development

Fishing, one of man's earliest pursuits, has been undergoing steady improvement. Evidence of the use of fish nets was found in the ruins of the Stone Age. Reels, netting needles, and netting were depicted in Ancient Egypt. Explorers and early settlers have turned up fish netting used by primitive people as widely separated as the Arctic Ocean and the South Seas. Even today no one knows quite how the knowledge of net-making spread so far.

Although the early nets were contrived of crude materials and designs, they were amazingly similar to those of the present day; in fact the netting knots are identical. This knot has several names, such as "trawler's knot," "sheetbend," etc., but is universally known as the "fishermen's knot" or "weaver's knot."

Machines for the knitting of fish nets were invented in the last half of the 18th century, but were not successful until 1840, when they were capable of reproducing the hand-knit nets. Some of these early machines are thought to be still in use. This invention marked the beginning of a new era in commercial fishing. Since that time and especially in recent years, with the use of readily available materials, the commercial fisheries have grown and developed.

The period from 1929 through 1949 has been one of tremendous development in technical advances throughout the fisheries of the United States. This was made possible, for the most part by the numerous improvements in the methods of capture with the aid and application of technological research.

The fishing gear now in use in the United States represents an investment of over $50,000,000 (see Table 57, p. 231). The netting alone is valued at about half this amount; cordage and rigging accessories the remainder. As nearly as can be estimated gear will last less than a year; the biannual replacement is, therefore, approximately 100 per cent.

Prior to December 7, 1941, nearly 50 per cent of the netting sold in this country was imported. World War II cut off all such importations and the domestic manufacturers, in addition to adequately supplying the needs of an expanded fishery, were faced with the problem of producing large quantities of camouflage netting as well. In the United States netting consumption, principally cotton, amounts to approximately 7 million pounds a year. Cordage, principally Manila hemp, is used by the fishing industry at the rate of 8 million pounds annually.

During the past two decades legislation enacted for the alleged purpose of con-

servation has favored, if anything, the use of improved gear; very few restrictions prohibit the use of popular types. Such minor restrictions as have been applied concern mesh sizes, seasonal operations in an area, or the limit of the number of gear to be used. Generally speaking, improvements and the adoption of new forms have been encouraged, with a view to increasing efficiency and production within economic and natural limitations.

FIG. 13–1. Indian fishermen, exercising treaty rights, dipping salmon from the Columbia River at Celilo Falls.

Outstanding among the improvements and changes in types of fishing gear since the turn of the century is the widespread adoption of the otter trawl. This type of net has been responsible for the large catches of ground fish, and its prototype, the shrimp trawl, has played a prominent part in the development of the shrimp fishery.

Other gear improvements can be noted in the long line fisheries for halibut and salmon. The development of the "gurdies," which are now operated mechanically, has added greatly to the efficiency of this method of fishing. Certain fish pots, formerly constructed of wood slats or rough birch boughs, are now made of wire which wears better and enables the fisherman to operate more pots in less time.

There has been a marked decline in the trawl line and long (hand) line fisheries in the New England area; in Boston and Gloucester it is practically ex-

TABLE 59. FISHERY APPARATUS OF THE UNITED STATES—SHOWN BY NUMBERS AND GEOGRAPHICAL DISTRIBUTION.

Classification of Fishing Apparatus	New England (1945)	Middle Atlantic (1945)	Chesapeake Bay (1945)	So. Atlantic and Gulf (1945)	Pacific Coast (1945)	Great Lakes (1940)*	Mississippi River (1931)*	Alaska (1945)	Total
Nets:									
Haul, beach and stop seines	135	126	495	739	365	169	1,013	99	3,141
Purse seines	95	41	16	52	497	—	—	704	1,405
Lampara and paranzella nets	—	—	—	—	114	—	—	—	114
Otter-trawl nets	883	343	44	9	747	—	—	—	2,026
Shrimp-trawl nets	1	—	—	4,348	—	—	—	—	4,349
Beam-trawl nets	—	—	—	—	14	—	—	10	24
Gill nets: drift, anchor, etc.	3,440	3,253	2,226	6,036	11,038	106,031	101	2,226	134,351
Trammel and bar nets	—	—	138	900	84	75	518	—	1,715
Pound and trap nets	135	187	1,930	145,740	53	8,336	374	410	157,165
Weir nets (brush incl.)	141	24	—	—	6	—	—	—	171
Stop and bag nets	115	17	7	—	2	—	—	—	141
Fyke net	78	1,034	1,694	471	2,146	1,787	32,541	—	39,751
Cast and reef nets	—	—	—	180	47	—	—	—	227
Dip, brail, and scoop nets	663	114	2,518	2,410	2,625	—	191	—	8,521
Lines:									
Hand lines	3,329	408	280	4,347	4,388	—	67	160	12,979
Trawl lines (incl. skates)	24,169	296	—	26	38,321	—	—	4,790	67,602
Troll lines	50	765	—	1,521	10,594	60	—	3,612	16,602
Tuna lines	—	—	—	—	15,718	—	—	—	15,718
Trot lines	—	86	1,761	3,075	—	2,258	17,129	—	24,309
Hooks (for above lines)	1,338,477	157,733	2,130	143,891	1,249,771	615,839	2,459,112	130,700	6,097,653
Baits and snoods	—	36,600	1,315,650	1,542,930	—	—	—	—	2,895,180
Pots and traps:									
Lobster	464,826	13,010	—	8,900	5,199	—	—	—	491,935
Eel	2,493	1,417	18,080	555	—	—	—	—	22,545
Crab	521	—	319	10,228	54,463	—	—	3,702	69,233
Fish	43	13,435	1,378	10,920	—	—	—	—	25,776

Crawfish	—	—	—	—	1,250	700	456	—	2,406
Other [1]	971	—	885	—	125	—	3,769	—	5,750
Dredges:									
Clam	92	96	20	6	—	—	—	—	214
Mussel	—	—	—	—	—	—	440	—	440
Oyster	58	242	483	769	46	—	—	—	1,598
Crab	—	27	168	—	—	—	—	—	195
Scallop	3,082	28	—	72	—	—	—	—	3,182
Spears and harpoons	295	49	—	531	84	—	12	—	971
Crowfoot bars and scrapes	—	—	277	—	—	22	4,480	—	4,779
Tongs, rakes, and shovels	2,132	9,462	7,592	3,037	12,036	—	245	—	34,504
Hoes, forks, picks, and crabs	2,885	104	—	208	—	13	3,679	—	6,889
Diving outfits	—	—	—	67	72	—	—	—	139

[1] Turtle (880), octopus (125), periwinkle and cockle (960), box and slat traps (16), baskets (3,769).

Source: "Fishery Statistics of the U. S., 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18**.

* Latest data available.

tinct in the large vessel fishery. These same boats can now be seen in the otter-trawl fleet, having been converted by the owners. This shift was necessary so that the vessels would be able to obtain catches large enough to maintain themselves economically.

The magnitude of the ground fish fishery has created special problems in applying conservation measures, whereas the line-trawl hooks were to a degree selective in the size of the fish caught, otter-trawl nets gather everything in its area of tow. Changes in the construction of the otter-trawl nets became necessary. A larger mesh in the cod end, or "fish bag," was introduced as a means of allowing a major portion of the small unmarketable fish to escape without seriously affecting the quantity of marketable fish caught.

Fishing-gear regulations, which have become necessary in recent years, are evident in the salmon and halibut fisheries of the Northwest. In the salmon fishery restrictions applying to the length of the season are essential to maintain a proper level of abundance, and they are rigidly enforced by the United States Government. In the halibut fishery the fishing season, the number and types of gear employed, and the area in which the fish may be taken, are regulated by International Treaty. Regulations and limitations on pound nets, gill nets, and traps are imposed when necessary by the various states in which they are operated, either through licensing, adoption of mesh size specification, or complete restriction.

In general these regulations have contributed to the over-all improvement of the fisheries. Despite the adoption of essential fishery regulations, both United States Government agencies and individual state agencies encourage developments in the fisheries everywhere. Their purpose is not to create hardship for the fishermen, but to prevent any possibility of it in the future.

Relative Importance of Fishing Gear

The numbers and forms of fishing gear employed in various sections of the country, based on the latest records available, are shown in Table 59 (p. 236). In this table one can see the wide variety and form of fishing gear used to catch over 4½ billion pounds of fish and shellfish annually. This catch is valued at 270 million dollars* by the fishermen engaged in the commercial fisheries.

Approximately 85 per cent of the total annual catch is taken with netting apparatus. Purse seines account for 52 per cent of this, otter trawls 25 per cent, pound nets and traps 11 per cent, gill nets 6 per cent, and haul seines and stop seines 3 per cent. The remainder of the catch is made as follows: lines 8.6 per cent, dredges 1.5 per cent, pots and traps 1.3 per cent, and tongs, rakes, shovels, crawfoot bars, and scrapes 3 per cent.

The total catch classified by the gear with which it was taken is given in Table 60, shown in the percentage yielded by each type. Thus it is clearly evident that the purse seines play an important role in the total annual production and that the otter-trawl nets are growing so in popularity and effectiveness as to rank second in importance.

In 1918 1,287 otter trawls were reported to be operating in the fisheries, and they accounted for less than 5 per cent of the total catch. They could hardly be listed as one of the leading gear.

* 1945 catch records, U. S. Fish and Wildlife Service (1949).

TABLE 60. IMPORTANCE OF VARIOUS TYPES OF FISHING GEAR IN THE UNITED STATES FISHERIES, SHOWN BY CATCH AND PERCENTAGE EACH CONTRIBUTES (1945 DATA).

Classification of Fishing Apparatus	Total Pounds Caught by Gear Specified	Per Cent of U. S. Total, Including Alaska
Nets:		
Purse seines	2,067,895,678	45.30
Otter trawls (incl. shrimp)	796,977,900	21.70
Pound and trap nets	366,479,041	8.00
Gill nets	253,713,759	5.60
Haul, beach, and stop seines	124,456,617	2.70
Dip, brail, and scoop nets	51,932,745	1.10
Weir nets	47,102,000	1.00
Fyke nets	25,751,704	.80
Trammel nets	11,977,506	.30
Paranzella nets	6,588,500	.20
Cast and reef nets	2,340,900	.04
Beam trawls	1,499,891	.03
Stop and bag nets	603,300	.02
Lines:		
Hand, trawl, trot, etc.	393,946,021	8.60
Dredges:		
Clam, oyster, scallop, etc.	67,966,900	1.50
Pots and traps:		
Lobster, eel, fish, etc.	59,067,075	1.30
Other gear:		
Tongs, rakes, and shovels	46,102,506	1.00
Crowfoot bars and scrapes	22,349,550	.50
Hoes, forks, picks, and grabs	16,209,336	.40
Spears and harpoons	4,526,350	.10
Diving outfits	689,400	.02

Source: "Fishery Statistics of the U. S., 1945," U. S. Fish and Wildlife Service, *Statistical Digest,* **18.**

TABLE 61. COMPARISON OF IMPORTANCE OF CERTAIN FISHING GEAR IN 1918 AND 1945.

Gear	1918 Per Cent	1945 Per Cent
Purse seines	30	45.3
Otter trawls	less than 5	21.7
Pound nets, etc.	17	9
Gill nets	10	5.6
Lines	18	8.6
Dredges, tongs, etc.	19	3.5
Quantity of total accounted for	99	93.7

Vessels, Boats and Men in Commercial Fisheries Operations

Fishing boats are divided into two groups: Those over 5 net tons, which must be registered and are documented by the proper United States Government authorities, are classified as vessels. Boats under 5 net tons need only be registered in the state in which they operate. Such registration is principally a safety measure, thereby enabling Federal and State officials to maintain records of all marine activities. Boats without power, under one net ton, and less than the length specified by the state (usually 20 feet) are not required to register. The foregoing classifications and registrations must be complied with, irrespective of the motive power (i.e., gas, Diesel, steam, or sail).

The number of vessels and boats which were operated in the commercial fisheries during 1945, as well as the new commercial fishing vessels over 5 net tons which received their first documents from January 1946 through December 1949, are shown in Table 62. These 4,554 additional vessels represent 65 per cent of the entire fleet of this class in 1945.

The majority of fishing craft in the registered vessel group are powered with Diesel motors. This type of motor has proven to be the most efficient and economical to operate, in addition to being subject to fewer mechanical breakdowns. It figures prominently in the over-all development of United States fisheries and is gaining world favor. Gasoline motors are popular in the low tonnage group.

Steam power is practically nonexistent today because it requires full time attendance by one or more men and space for fuel and water which can be more effectively utilized as cargo space. Although a total of 34 steam vessels are shown in Table 62, most of them are in the Great Lakes fishery, where any new vessels built since 1940 have been powered by gasoline or Diesel motor.

While unregistered and under-tonnage boats constitute 90 per cent of the entire fleet, it is interesting to note that approximately 80 per cent of the catch is taken by the registered vessel group alone. This is attributed not only to the size and range of these vessels, but also to the heavy gear employed. Modern navigational aids have also been a contributing factor, for they reduce the time which might otherwise be lost on account of bad weather conditions.

A total of more than 140 thousand active fishermen on boats, vessels, and shore make their living from the commercial fisheries. Operating about 625,000 pieces of gear along the shores of the oceans, lakes, and rivers of the United States and Alaska, as well as manning the boats and vessels on the open sea, they account for more than 4½ billion pounds of fish a year.

Fibers Used in the Commercial Fisheries

The fibers employed in the manufacture of the twine, lines, nets, and cordage used throughout our commercial fisheries must meet the most exacting requirements. They must not only be tough, durable, and reliable, but must also withstand the effects of alternate water immersion and atmospheric exposures, in addition to abrasion.

Since the fibers in use during the past several centuries are almost identical with those which are in use today, it appears that they are well-chosen. There are three general classifications: hard or leaf fibers, such as Manila, obtained from

TABLE 62. NUMBERS AND DISTRIBUTION OF FISHING VESSELS AND FISHERMEN ENGAGED IN THE COMMERCIAL FISHERIES OF THE UNITED STATES.

Classification of Vessels and Boats	New England (1945)	Middle Atlantic (1945)	Chesapeake Bay (1945)	So. Atlantic and Gulf (1945)	Pacific Coast (1945)	Great Lakes (1940)*	Mississippi River (1931)*	Alaska (1945)	Total	
Fishing operations:										
Vessels—Registered, over 5 net tons										
Motor	828	482	200	1,686	2,141	469	—	936	6,742	
Steam	—	1	2	—	1	30	—	—	34	
Sail	—	7	97	49	—	—	—	—	153	
Total	828	490	299	1,735	2,142	499	—	936		6,929
Additions to vessel fleet,**										
Documented since 1945: (motor)										
1946	86	74	71	351	375	76	—	19	1,052	
1947	75	70	97	490	411	74	—	47	1,264	
1948	52	40	59	541	348	51	—	81	1,172	
1949	35	44	87	369	327	38	—	96	996	
Total	248	228	314	1,751	1,461	239	—	243		4,484
Boats—Unregistered, under 5 net tons										
Motor	5,938	3,343	7,447	7,999	6,781	1,186	4,426	1,347	38,467	
Other (oars-sails)	4,035	2,034	5,821	8,372	862	599	10,120	1,399	33,242	
Total	9,973	5,377	13,268	16,371	7,643	1,785	14,546	2,746		71,709
Accessory boats	241	133	44	314	817	—	—	—		1,549
Lighters and scows	—	—	—	—	—	—	—	250		250
Fishermen:										
On vessels	5,377	2,731	1,647	5,491	10,894	1,694	—	8,261	36,095	
On boats and shore	15,009	8,117	16,026	24,206	23,134	3,448	15,884	No Data	105,824	
Total	20,386	10,848	17,673	29,697	34,028	5,142	15,884	8,261		141,919

* Latest data available.

** Source: Monthly supplement to Merchant Vessels of the United States, Bureau of the Customs. Vessels have been assigned to the various sections on the basis of their home port.

the tissues of the leaves of certain tropical plants; soft or bast fibers, such as linen, obtained from the main stalks of plants, and cotton, obtained from seed hairs; and synthetic, or man-made fibers, among which nylon is outstanding. It is interesting to note that all of the natural fibers are composed principally of cellulose (from a vegetable origin).

Manila. Aside from some use in the construction of large sized otter trawls, Manila (and sisal) fiber is employed almost entirely in the manufacture of marine cordage. More Manila hemp (although it does not grow near Manila and is not hemp) has been used for marine cordage during the past 100 years than all other fibers combined.

The sizes of Manila twines utilized in netting are designated by the number of feet of single yarn and the number of cords, or strands, in the twine. For example, $^{1200}/_{3}$ means a 3-stranded twine made of Manila that runs 1,200 feet per pound in the single yarn. Therefore, the 3 cord would run approximately ⅓ of 1,200, or 400 feet per pound. The English system describes this twine by yardage of the completed twine (e.g., 75 yards/2 cord would be a 2-stranded twine running 75 yards per pound, etc.).

Cordage is classified by thread count and diameter or circumference measurement. For example, a 6-thread rope is ¼ inch in diameter and ¾ inch in circumference. Thread count is seldom used, however, when the diameter is more than ½ inch.

Cotton. The widespread use of cotton fibers during the past 5,000 years can be accounted for by its wild growth in nearly every tropical country and its ready

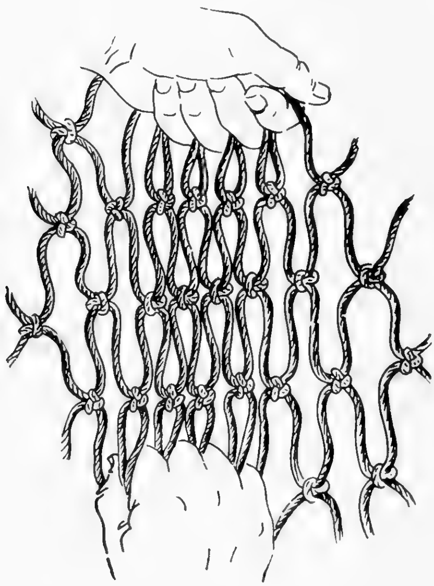


FIG. 13–2. Netting as it comes off the looms, sometimes called "crosstwine."

adaptability to cultivation in semitropical zones. This abundance, as well as inherent quality, make this fiber the most important in the United States today. Over 70 per cent of all netting used in the commercial fisheries is made from

cotton. Although cotton is actually a seed-hair fiber, it is grouped with the soft (bast) fibers, which are normally derived from the main stalks of plants.

Cotton-twine sizes are designated by two numbers, (1) indicating the weight of the yarn and (2) the number of strands of yarn in the twine. The weight is the number of 840-yard hanks in a pound. For example, $^{10}/_{12}$ twine is composed

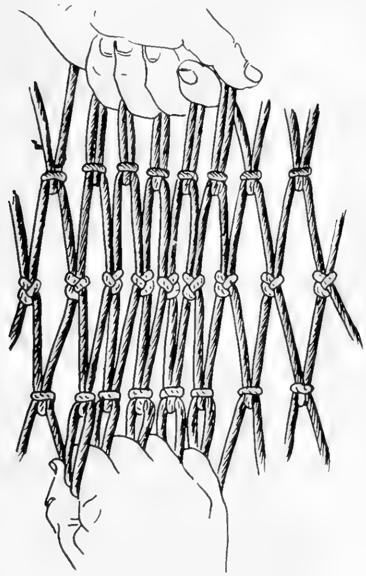


FIG. 13–3. The same netting shown in Fig. 13–1 with tension reversed illustrates method of fishing. Note how straight twines allow meshes to close uniformly.

of yarn of which 10 hanks, or 8,400 yards, weigh 1 pound, indicated by the 10. Three strands of 4-ply thread twisted together is indicated by the number 12; thus, there are 12 threads of number 10 yarn in $^{10}/_{12}$ twine. Ten-yarn twines are the most commonly used. They are cable, or right twist, and are usually referred to only by the number of strands or threads (e.g., $^{10}/_{6}$ cable is called 6 thread, $^{10}/_{24}$ is 24 thread, etc.).

Due to the need of various degrees of twist for cotton-netting requirements, cotton twine is made up in different lays. The most common ones are soft, medium, and hard; others are known as hawser, a left lay, and plain.

Linen. It is believed that primitive man first utilized the flax plant for various fishing and hunting requirements many centuries before the inner filament was discovered to be a textile fiber. It was learned that by weathering flax straw, long, tough, but pliable fibers, which did not decompose could be extracted. It was also discovered that these fibers could be twisted together to form a thread, which in turn could be further twisted together, or woven.

Despite the fact that linen is perhaps the oldest fiber known and has excellent qualities for marine uses, its use in the commercial fisheries is limited because of the high differential in cost as compared with cotton. About 90 per cent of all the linen in use in the United States today is imported.

Linen thread sizes are listed by leas and the number of cords; one lea equalling 300 yards of single ply yarn per pound. Therefore, a $^{12}/_{3}$-linen size shows the thread to be made from 12-lea yarn twisted into 3 cords. To obtain the number

of yards of linen in a given pound of thread, multiply the lea by 300 and divide by the number of cords. For example, one pound of 40/8-linen thread would be 1,500 yards long.

Synthetic Fibers. As far as is known the first synthetic, or man-made, fiber to be successfully developed was called "artificial silk" and was shown at the Paris Exhibition in 1889. Though a poor example, it was nevertheless the beginning of the modern synthetic fiber industry.

Nylon, first called "Fiber 66," made its appearance in 1938. An American invention, it has no counterpart in any other product in the world. This fiber can be best characterized by its extreme toughness, strength, and light weight. Since World War II started at about the time that nylon was introduced into the fishing industry, it was restricted for use by the armed services. In 1946 these restrictions were lifted, making it available for the second time.

Nylon appears to possess the best characteristics for displacing natural fibers in marine fisheries' applications. Because at the time of this writing only a small quantity has actually found its way into the fishing industry, it is difficult to predict its future.

Another synthetic fiber, known as "Orlon," was announced late in 1948. Since it has been reported to have been developed for marine uses, it may compete with nylon in this field.

Although nylon fibers are processed into twine, rope, etc., in much the same manner as the natural fibers, they are classified into various sizes by the term "denier." The size, therefore, is the weight of a 450-meter (1,500 feet) skein of fiber in deniers, 1 denier equalling 5 cg, 20 deniers equalling 1 g (1/454 pound). They can be sized by weight because the diameter of nylon fibers is so uniform.

Netting Terminology. Fishermen generally call fish netting "webbing" or "twine" to distinguish it from a rigged net. Rigged nets are "hung" nets and include not only the webbing but all necessary attachments, such as floats, sinkers or leads, and the cordage to which they are all secured. The term "gear" is used when referring to a complete net.

Netting manufacturers produce the webbing in long continuous sheets, as in other types of textile manufacture. Instead of rolling it on spools as it comes off the loom, it is laid in folds. Because of its bulk the netting is pressed into bales before shipping. It is sold by the pound.

When finished nets are ordered, the manufacturer requires from the customer a pattern containing all the specifications from which the net is tailored. Standardization of fish nets is practically nonexistent, with the exception of such gear as otter trawls, fyke nets, etc. For this reason the majority of netting is sold as straight webbing, conforming to the mesh and twine sizes specified. The depth of a net is actually the width of the webbing as it comes off the loom. The purchase of netting is, for the reasons shown here, a matter of importance not only to the fishermen, but to the manufacturer as well.

The size of a mesh is always given as the stretched measure (i.e., a mesh measuring 1 inch on each of the four bars, or legs, would be termed a 2-inch mesh). Measurements are taken from the center of the upper knot to the center of the lower knot by inserting a thin ruler inside the upper knot, drawing the legs of the mesh together until they are taut, and recording the length to the outside edge of the lower knot. In other words the mesh size includes only one full knot.

The length or width of a net is often expressed in feet, yards, or fathoms. Given the size of mesh it is a simple matter to transpose any of these into number of meshes. For example, a web 50 feet long composed of 3-inch meshes would be 200 meshes in length. Fishermen usually take measurements by counting meshes.

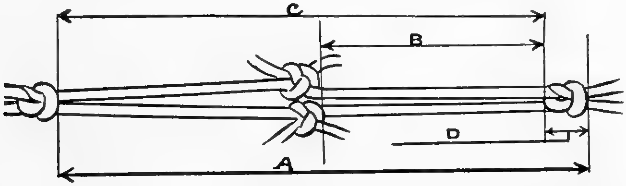


FIG. 13–4. Units of measurement sometimes used in netting specifications. (a) Recognized method used by manufacturers and fishermen. (b) Mesh bar. (c) Inside length of mesh. (d) Size of knot.

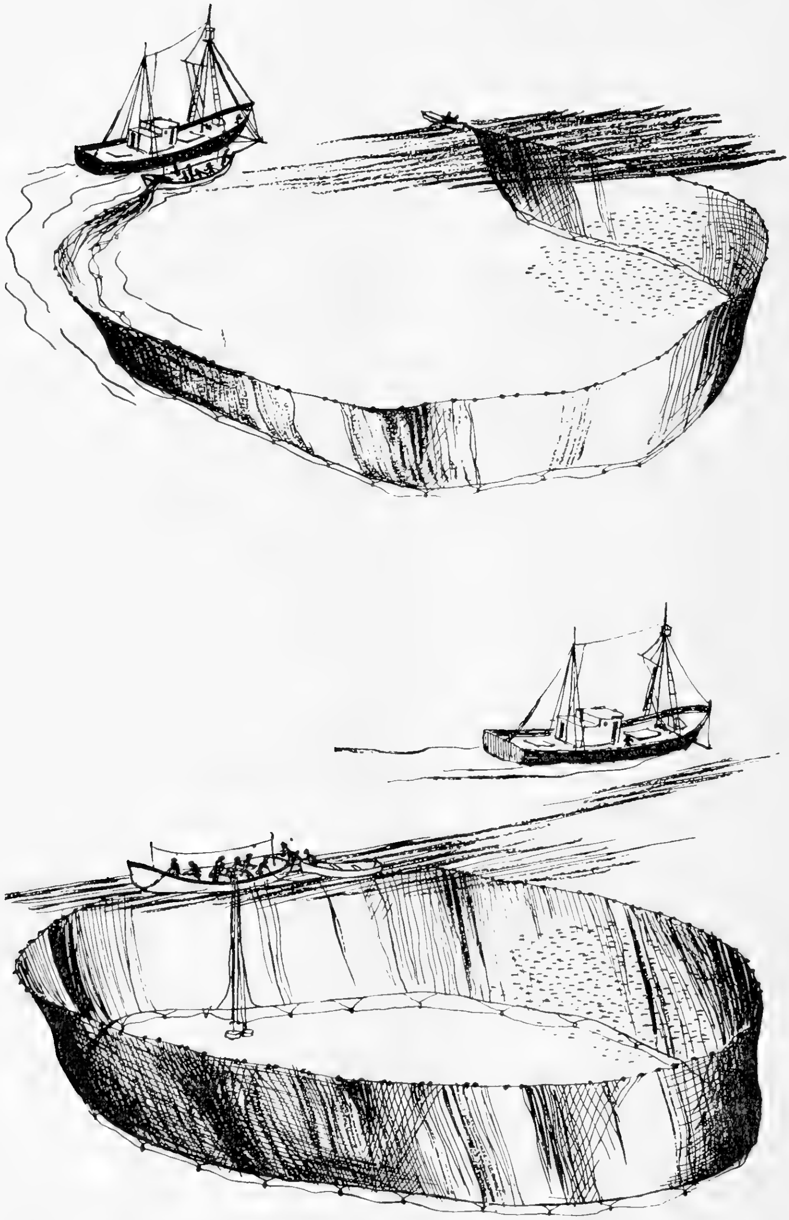
Apparatus of Capture

Fish nets fall into three general classifications: traps, seines, and gill nets. While there are many other styles of nets which may not seem to fit into these categories, they are nevertheless shown to follow by their modus operandi: Otter trawls are actually bag seines; fyke nets are traps; trammel nets are a form of gill net, etc.

Purse Seines. The purse seine, in use throughout the United States and Alaska, is accredited with more than 45 per cent of the annual total catch; it is by far the most productive kind of gear in use. Generally used in deep water, either in gulfs or bays, or at sea at varying distances from shore, it is employed in the capture of the pelagic fishes which school at or near the surface. The seine is set out in such a way as to encircle the school; the bottom of the net is then pursed to prevent the fish from diving and escaping. It is also used extensively in the pilchard, menhaden, tuna, mackerel, salmon, and herring fisheries. Its construction varies somewhat with the particular fishery in which it is employed, but its operation is essentially identical in all.

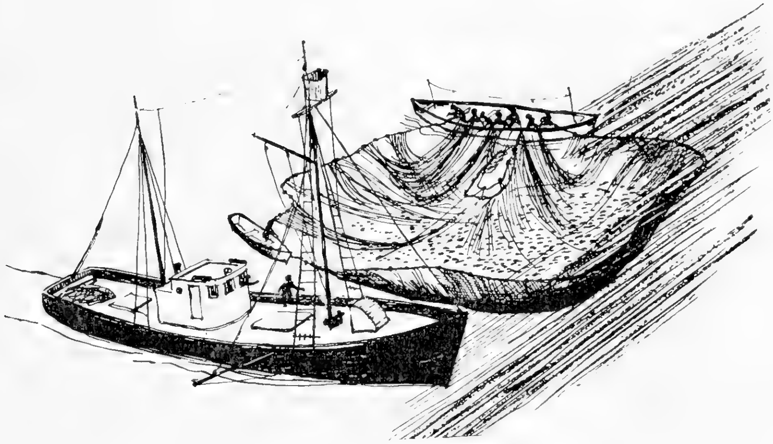
A purse seine might be described as a long sheet of rectangular netting, as much as 500 fathoms in length and 50 fathoms in depth, set vertically in a circular fashion in the water. It is so hung that the wall of netting will belly out in the water. To facilitate setting and pursing, the take up is greater on the lead line, which is about 10 per cent shorter than the netting. The upper edge is buoyed by corks which support the weight and the lower edge is weighted with leads which keep the wall of webbing in an upright position. Attached at intervals to the lead line are bridles supporting round metal rings through which is run a purse line. Each end of the purse line is run through a weighted pulley, located on either end of the seine, and up to the seine boat or vessel. After the seine has been set in a circle, the ends of this line are hauled together with the aid of a powered winch, which closes in the bottom edge of the netting and forms a bowl-shaped pocket from which the fish cannot escape.

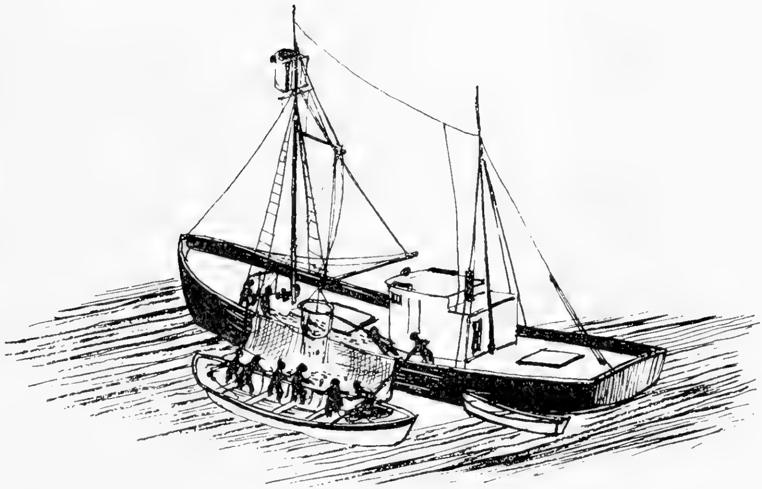
The webbing is then hauled into the vessel or seine boat until all but the bunt, or heavy twine section, is back. This is usually located at one end of the seine. After the fish are crowded into the bunt, they are brailed into the vessel and



1. Coming to the dory, the seine nearly paid out, the vessel prepares to cast off the seine boat.
2. With the mackerel school surrounded, tom weights are dropped in preparation for pursing operations.

FIG. 13–5. (1–4) Atlantic Coast mackerel pure seine operations. (*Courtesy R. J. Ederer Co.*)





3. With the pursing operations nearly completed the vessel is preparing to pick up the seine at the bunt.
4. "Brailing" the fish onto the deck.

placed in the hold. Speed is a factor in this operation and the time required for setting and pursing usually varies from 15 to 20 minutes. Brailing time depends on the quantity of fish taken, requiring as much as 3 hours when 100,000 pounds or more are captured. After the set the seine is stacked in a manner to facilitate reoperation at a moment's notice.

Purse seines, as operated in the menhaden, mackerel, and herring (sardine) fisheries on the Atlantic Coast and in the Gulf of Mexico, use 1 or 2 seine boats. The seine is stowed in the seine boats while at sea and on the deck of the vessel at other times.

When a school of fish is sighted from the crow's nest, the vessel is maneuvered into a favorable position to head off the school. A boom about 20 feet long, which is attached to the seine boat, is swung out from the base of the mast. Immediately one end of the net, including the purse line, is put into the water and held in position by a small dory. The vessel then makes a circle around the school while the seine is rapidly paid out from the seine boat. When the circle is completed, the ends of the seine and purse line are brought together in the seine boat and the vessel and dory move off. The purse line is drawn in with the aid of a small gas engine, taking only a few minutes, and the excess netting is hauled by hand. The fish thus concentrated in the bunt are brailed immediately in order to prevent them from drowning. Seine boats are about 40 feet long, with an 8 or 9 foot beam, and 3 or 4 feet deep. They are of open double-end construction, quite similar to the average lifeboat.

When 2 seine boats are used, half of the seine is stowed in each. This system is still used in the menhaden fishery where they are towed astern tandem fashion. The seines in this instance are made with the bunt in the center. Many of these seine boats are powered with gas engines.

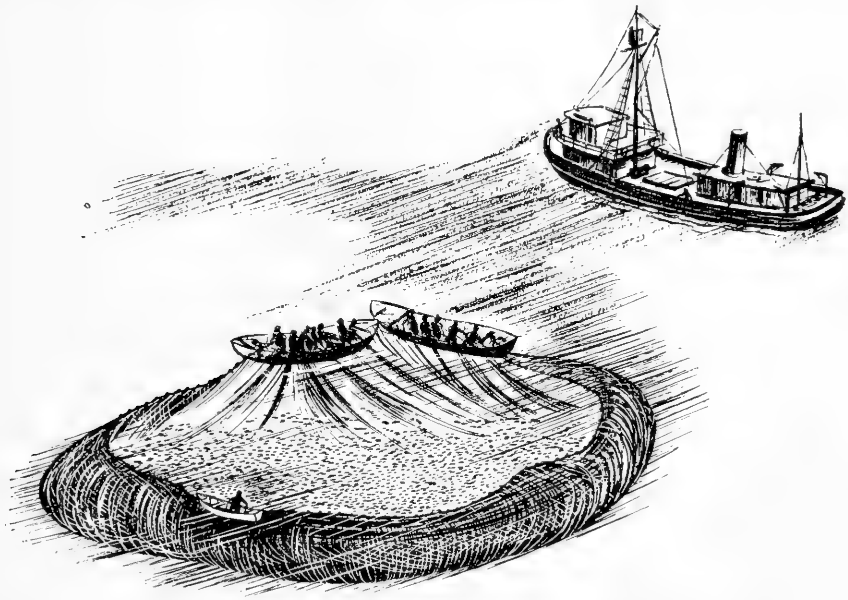
In the West Coast tuna and pilchard fisheries the purse seines are operated directly from a wide turntable in the stern of the vessel. The seines are set from the stern and pursed by deck winches. A boom from the mast speeds the work of hauling in the excess netting after a set, but otherwise its operation is similar to other types of purse seining.

Tuna Seines. These seines vary in size from 350 to 500 fathoms in length and from 25 to 50 fathoms in depth. The average seine consists of 5 strips of netting, each 100 meshes deep, which are laced together and run longitudinally the length of the net. The net is made of 42-thread medium cotton twine with 4½-inch meshes. The bottom strip of 60-thread medium cotton with 8-inch meshes is 50 meshes deep. This is hung to ⅝-inch and ¾-inch Manila ropes, buoyed on the upper line with 6,000 special seine corks 6 inches in diameter, and weighted on the lower line with 2,500 pounds of 4-ounce seine leads. Approximately 225 galvanized iron purse line rings, ⅝ inches thick and 4 to 6 inches in diameter, are attached by 15-thread Manila rope bridles to the lead line. The Manila or steel purse line, 1½ inch in diameter, is rove through these rings and the seine is complete. When fully rigged and treated with coal tar, its total weight is about 25,000 pounds (12½ tons), of which one third is netting.

Menhaden Seines. These seines, especially designed for this fishery, average about 300 fathoms in length and 20 fathoms in depth. They are constructed of 2-inch mesh, 20/9 hawser lay wings and 20/12 hawser lay in the portion around the bunt. The bunt, located in the center section, is made up of strips of 12-, 15-,

18-, and 24-thread medium seine twine, all 2-inch mesh. This bunt is 14-fathoms square and is placed in the upper center section of the seine.

To prevent twisting, menhaden seines are hung to two 9-thread, right and left lay Manila ropes, to which are attached 3,800 4-inch and 4½-inch special seine corks. The 15-thread Manila rope on the bottom edge is weighted with approxi-



(*Courtesy R. J. Ederer Co.*)

FIG. 13–6. Menhaden purse seine with two seine boats hauling in net after a successful set. Striker boat supports cork line until netting is hauled back, the fish are then "brailed" into the vessel standing by.

mately 140 pounds of #6 leads. A hundred 1-pound brass rings of 6 inch diameter serve the ⅝-inch diameter Manila purse line.

Pilchard Seines. These seines are also known as sardine seines and are constructed from 5 strips of netting laced together. In a seine 240 fathoms long by 24 fathoms deep the first, or top, strip is 12-thread Manila twine, of 1⅜-inch mesh, 400 meshes deep; the second has the same mesh size and count, but is of 9-thread medium twine. Both are 210 fathoms long. The bunt, 30 fathoms long and 800 meshes deep, of 1⅜-inch mesh and 15-thread twine, is attached to the end of these two strips. The third and fourth strips are each 400 meshes deep, of 1⅜-inch mesh and 9-thread medium twine, while the fifth, or lower, strip is only 25 meshes deep, of 8-inch mesh and 72-thread medium twine, and is known as the lead line strip.

A typical sardine seine of this size, as used in the California fishery, is hung to a ¾-inch diameter Manila rope. This rope is strung with 6,000 seine corks for buoyancy and weighted with 1,600 pounds of 4-ounce seine leads attached to a ⅝-inch Manila rope. Approximately 160 galvanized-iron purse rings, 4 to 6 inches in diameter, are required to carry the 1³⁄₁₆-inch diameter steel or Manila purse

(Courtesy U. S. Fish and Wildlife Service)

Fig. 13–7. The pilchard are surrounded by the purse seine. They are then brailed from the seine into the vessel and carried to the cannery.

line. The netting alone in such a seine weighs almost 7,500 pounds, and the total weight, fully rigged and treated with tar, amounts to 10,500 pounds.

Mackerel Seines. The average mackerel purse seine used in the North Atlantic is 250 fathoms long by 18 fathoms deep. Except for the bunt, it is made of $^{20}/_{6}$ medium twine, of $2\frac{1}{8}$-inch mesh, in one long continuous sheet or web. The bunt, located at one end, is usually of 12- and 15-thread medium twine, of $2\frac{1}{8}$-inch mesh. This is hung to Manila ropes, to which are attached corks at the top and leads at the bottom. This seine, when tarred, weighs about 2 tons.

Haul, Drag, or Beach Seines. These seines are found in every section of the United States and account for about 3 per cent of the annual catch. They are used in relatively shallow water along the shores of beaches, rivers, and lakes. They are operated by hand for the most part although the larger types may require teams of horses, tractors, or even power-operated winches. They vary in length from small minnow seines of 5 to 10 yards to others of 2,500 yards or more. The meshes in the netting range from $\frac{1}{2}$ to 6 inches. Haul seines are of various patterns, each designed for a specific purpose. In some cases the net is rectangular; others have tapering ends, the center being much deeper. Some have long tapering pockets, extending from the mid-portion, into which the fish collect and become entrapped. The center, bunt, or bag is usually of smaller meshes than the wings. The larger meshes in the wings have less water resistance, thus speeding the operation of the gear.

The smaller sizes, from 5 to 25 yards in length, with meshes of $\frac{1}{2}$ to 3 inches, are used principally in the interior lake and river fisheries, while the larger ones

are used in the coastal fisheries. The salmon fisheries in the rivers of the Northwest employ haul seines ranging from 500 to 800 yards in length and have a bag or pocket about 100 yards long.

(*Courtesy R. J. Ederer Co.*)

FIG. 13–8. Alaska beach seine. Nets are set from shallow draft boats around the fish and hauled manually to the shore. Cannery transport stands by to receive fish.

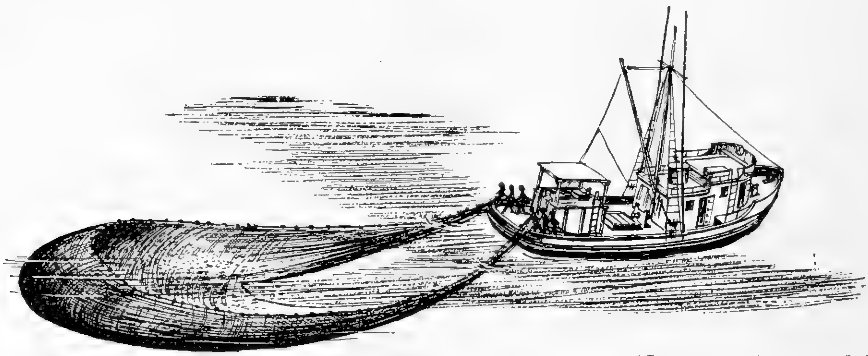
Lampara Nets. These nets, often referred to as "bait nets," apparently originated in Italy and were introduced into California about 1900 by immigrant fishermen. However, these nets have never been adopted in any other area of the United States.

They are constructed somewhat on the principle of a haul seine, except that the lead line is shorter than the cork line. This creates a bag in the back of the net for the collection of the fish. A lampara net is always hauled into a boat, and fishing is usually conducted in shallow water as it is desirable that the lead line be on or close to the bottom. It can be operated in deep water, however.

Lampara nets vary in size from 25 to 50 fathoms in length and 6 to 20 fathoms in depth. With the development of the tuna fisheries off the coast of Lower California, Mexico, and Costa Rica, these "bait nets," as they are most commonly called, are used by tuna boats and have been adapted to the areas where bait is abundant. The two popular types, representing the extremes in size, are known as "Galapagos" and "Anchovete" nets.

Lamparas are laid in a circle around the fish and pulled into the boat from both ends. The two ends, known as the wings, are of coarse mesh, 3 to 5 inches, so that they can be pulled in easily. The central portion, or bag, is of ¾- to 1-inch mesh and shaped like a scoop, the open end of which is pulled under the fish and then lifted out of the water. As the wings are pulled into the boat and the circle becomes elongated, the wings herd the fish into the bag and the lead lines come together, preventing the fish from diving as so often happens in purse-seine operations.

This type of net has certain advantages over purse seines: It costs less, can be operated by a smaller crew, and the absence of purse rings make it less likely to foul on the bottom when used in shallow water.



(*Courtesy R. J. Ederer Co.*)

FIG. 13–9. Pacific Coast lampara net in operation, for live bait.

Otter Trawl and Other Bag Nets. The earliest notice of the trawl net fishery in England, where it apparently developed, is found in the following exerpt from a petition to Parliament in 1376. ". . . some fishermen have during the seven years past, by a subterfuge, contrived a new instrument . . . made after the fashion of a 'dag' (drag) for oysters, which is unusually long, to which instrument is attached a net of so small a mesh, no manner of fish however small, entering within it, can pass out and are compelled to remain therein and be taken." Although the oyster dredge or drag thus appears to be of ancient origin, there is yet some question as to whether this gear or the seine first gave rise to the idea of the trawl.

About 1850 the otter trawl was in use. It resembled the present-day trawl, having doors fastened to the end of the wings, which by their kitelike action cause the mouth of the net to stay open without the necessity for beams. The name "trawling" was evidently derived from trailing or dragging, the trawl being a bag net which is towed, trailed, or trawled along the bottom, and so constructed as to capture those fish which naturally keep on or near the bottom.

"The remarkable development of beam trawling and subsequently otter trawling between 1850 and 1880 brought about a growth of prosperity without parallel in the history of the British fisheries." This statement was made in 1887 by Mr. J. W. Collins, former U. S. Fisheries Commissioner.

It is interesting to note a parallel development in U. S. fisheries between 1905, when the first otter trawler was built and put into operation, and 1930, in which year over 100 offshore and many times this number of smaller inshore trawlers were in operation. During 1930 these vessels accounted for 70 per cent of the entire ground fish catch in the North Atlantic. With it came new methods of handling fish ashore in mass quantities, adjusted to the continuous inflow of fresh fish. Its adoption has accounted for the development of many major U. S. fisheries, to such an extent that today otter trawls rank second in importance and are responsible for catching over 21 per cent of our total annual catch.

Trawl nets are one of the very few forms of gear which has become standardized. This is particularly true in the types employed in the ground fish (haddock and cod) fishery of New England. Here the size or type of trawl is designated by

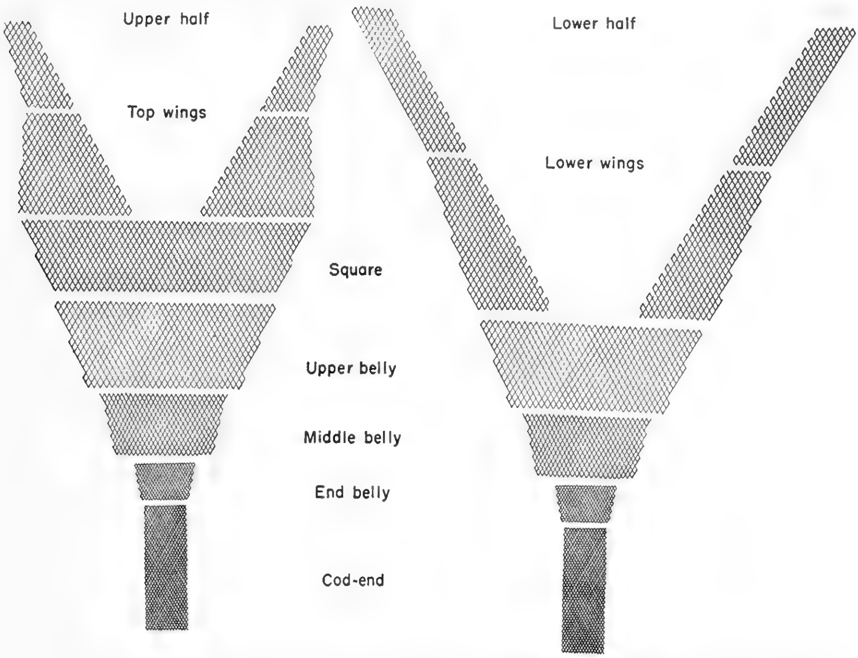


FIG. 13–10. The various sections of a trawl net before it is laced together. The variation in mesh size can be seen here.

a pattern number or name, as follows: #35, #36, #41, #41–A, #45–A, Portuguese type, and Iceland type. They are all made in sections which the fishermen lace together for convenience in replacement at sea as the need arises. Some nets, particularly the heavy Manila nets imported from England, Ireland, and Holland, are hand-knit. Although domestic nets are machine-knit, they are tailored and shaped by hand into the various sections.

Every otter-trawl net is made in two parts, referred to as upper and lower halves, each of which is made up of sections consisting of a pair of wings, a pair of bellies (middle pieces), and a single cod-end. In addition the upper half has an extra section known as the square, which gives the net the necessary overhang at the mouth of the net.

The meshes, which start at 5½ inches (6 inches in some nets) in the wings, are progressively smaller as the net narrows to the cod-end, where they are 2½ to 3½ inches. Reversely, the twine increases in size from the wings to the cod-end, the former being made from 1200-foot, 3-ply Manila, or 24- to 36-thread cotton, and the latter from 750-foot, 3-ply double Manila twine, or 96- to 120-thread cotton.

Combination steel wire and Manila strand ropes, with a fair degree of flexibility and great strength, are widely used as headropes and footropes, to which the netting is seized. They vary in diameter from ½ to 1 inch.

Spherical or cylindrical steel floats, about 6 inches in diameter, are attached for buoyancy to the headropes in the mid-section, or bosom. Heavy chains or other weights are attached to the footrope in the same area to aid in keeping this portion on the bottom. On rough fishing grounds large wooden rollers are fixed

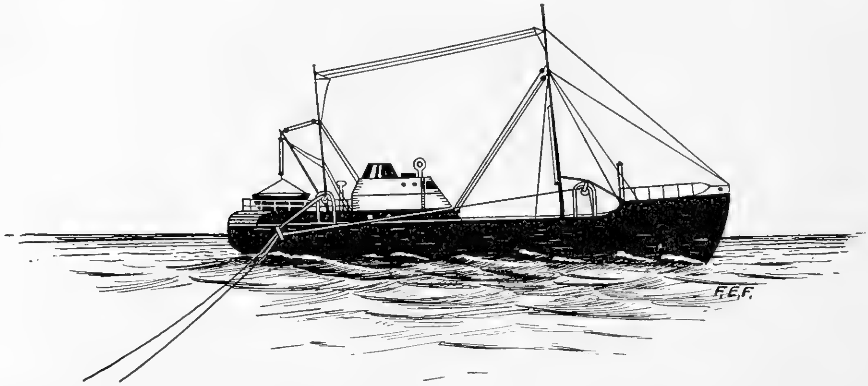


FIG. 13–11. Typical North Atlantic trawler, showing the "gallows," or frames supporting the towing cables, and their hook-up arrangement at the stern while fishing.

to the chains to assist the net in getting over rocks and debris and to prevent snagging and tearing. Raw, green cowhides are often fixed to the lower half of the cod-end to prevent the net from being chafed.

Two heavy wooden doors, 5 to 12 feet long, 3 to 5 high, and approximately 3 inches thick, to the bottom of which are attached steel runners or shoes, assist

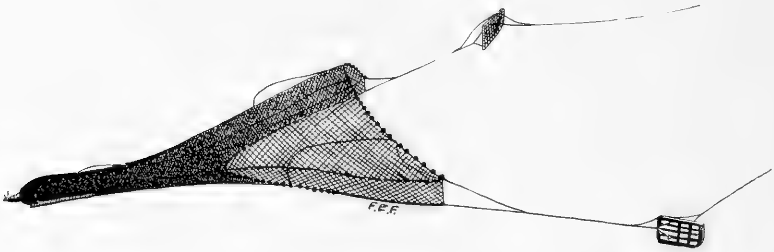


FIG. 13–12. Trawl net, showing the kiting action of the otter boards which keeps the mouth of the net open while in operation.

in keeping the net spread properly. Steel brackets or chains in the form of small bridles are fixed on either side of the doors in the mid-section. The bridles from the net wings are attached to the outer brackets, while the towing warps, usually made of steel, or heavy Manila, are attached to the inner brackets.

Trawl nets are almost always set from either side of the vessel, approximately midship. Special winches with separate controls on each drum enable the fishermen to have full control of the towing cables at all times. The cod-end goes overboard first, followed by the mid-section, square and wings, while the vessel

swings in a circle. The doors are then detached from the gallows frames through which the tow lines are rove on blocks. As soon as the doors are observed to be properly set and spaced, the warps are paid out rapidly and the vessel gains speed slightly. When the net sets on the bottom, the two warps are drawn to-

(Courtesy General Seafoods Corp.)

Fig. 13–13. Dumping otter trawl catch of haddock on deck of trawler.

gether near the stern of the vessel by means of a special hookup block. The vessel then proceeds on its course.

The process is reversed in hauling back after towing the net for ½ to 1½ hours. When the net is alongside the vessel, the doors are hooked to the gallows frames and the bulk of the net is hauled in with the help of the quarter ropes, which close the mouth of the net. When the cod-end is reached, a fish tackle is hitched to the splitting strap and the bag is lifted over the rail. Once in place over the deck the lower puckering strap on the cod-end is released, allowing the fish to fall into checkers on the deck. Before sorting and cleaning the fish for storage the net is set again, or if badly torn, the spare net on the opposite side of the

vessel is set. A buoy is often used to mark an area where fishing is good, so that the trawl may be set in the same spot.

As much as 25,000 pounds have been taken on a single tow and trips of 350,000 pounds or more have been made during a period of 8 or 10 fishing days.

Shrimp Trawls. Prior to the introduction of the shrimp trawl about 1912 almost the entire catch of shrimp had been taken by means of haul seines. By 1930 this gear accounted for less than 1 per cent of the total catch. The shrimp trawl was first used experimentally for the collection of marine forms at the Bureau of Fisheries Laboratory in Beaufort, North Carolina. Local fishermen, observing the large quantities of shrimp taken during these experimental hauls, devised large trawls for use specifically in shrimp fishing. By 1917 the use of the trawl had spread throughout the South Atlantic and Gulf States.

Shrimp trawls consist of a bag in which the fish are accumulated, a wing at either side of the bag for directing the shrimp into the bag, an otter board, or door, at the extreme end of each wing to keep the wings apart, and tow lines attached to the doors and secured to the vessel. They are essentially like a regular otter trawl, but are smaller in size and lighter in construction. Headropes, determining the spread of the net, vary from 20 to 140 feet and are usually selected to conform to the horsepower of the vessel on which it is to be used (i.e., 90 foot spread for a 60 horsepower vessel). The wings and body of the net are usually of 2½-inch mesh, constructed of 24- to 30-thread medium cotton twine, while the cod end is 2-inch mesh, of 54-thread medium cotton twine.

Paranzella Nets. The paranzella net is of Mediterranean origin and was first introduced into the fisheries of California in 1877 by an Italian fisherman. A somewhat primitive type of trawl net consisting of a flat triangular bag of webbing, it was developed from a beach seine or bag net, with a wide but low mouth. The net narrows rapidly from the wide mouth to the bag or cod-end, which is so arranged that it can be easily unlaced to discharge the fish when it is hoisted aboard the boat.

The net is made of cotton twine, having 4 to 8 different mesh sizes and ranging from 5 inches at the mouth to 1½ inches at the cod-end, the latter being made of much heavier twine. The mouth has a spread of about 50 feet and the net is about 150 feet or more in length. The towing warps are 1¼-inch diameter Manila attached to each side of the mouth of the paranzella, and these warps average between 400 and 500 fathoms in length.

Although there are no floats on the headrope (top rim of the mouth), the resistance of the webbing to the water produces all the lifting effect necessary. Metal weights or chains attached to the footrope result in an elliptical opening of the mouth as the net is towed.

The net is operated with two vessels, each towing one warp and following parallel courses about 125 fathoms apart. One of the vessels is usually larger than the other and is the one onto which the net is lifted. Tows or drags are of 1½- to 2-hours duration at 3 to 4 miles per hour, in depths of from 25 to 100 fathoms.

The principal advantage of this type of operation is the greater control of the net at practically any depth by the simple expedient of increasing or decreasing the spread between the boats and the speed at which they are towing. However, despite this net-controlling factor it is evident that the operation of two vessels

is uneconomical because there were only 9 paranzella nets in operation in 1945 as compared with several times that number in the past two decades.

Beam Trawls. Although the beam trawl is the gear from which the otter trawl was developed, it is rapidly being replaced by the latter gear because of the greater efficiency in handling and fishing. Nevertheless, beam trawls are in use today, though only in small numbers, in the North Pacific and Alaska fisheries.

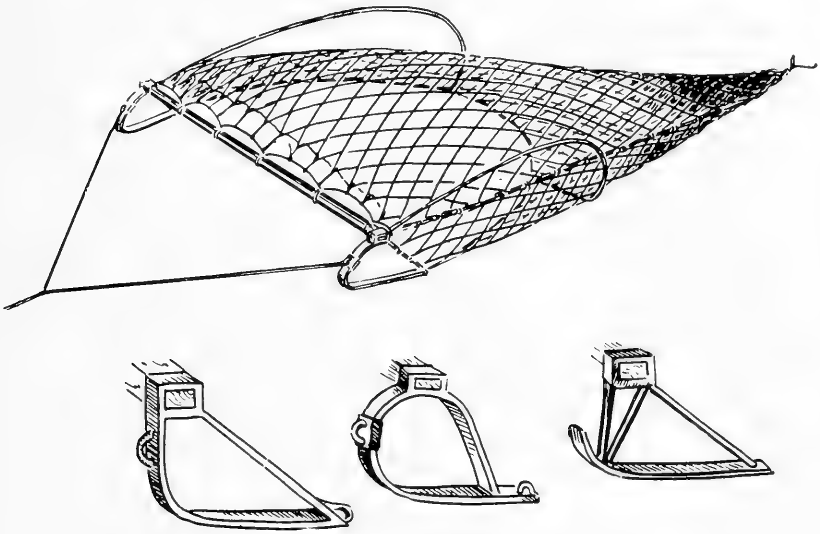


FIG. 13–14. Beam trawl and types of iron shoes or runners used.

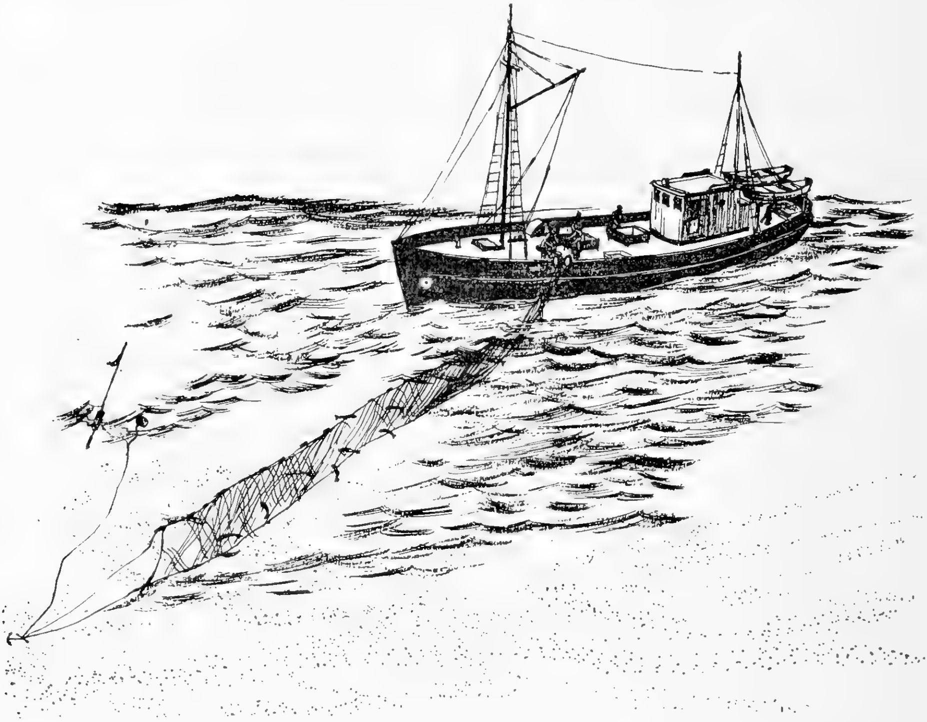
This gear consists of a wooden beam about 6 inches square and 20 to 25 feet long, to each end of which is fastened an iron runner. The beam sets about 3 feet off the bottom (the height of the runners). A bag of 1- to 4-inch mesh netting, about 25 feet long and tapering to a narrow pocket, is fastened to the beam and sides of the runners. Bridles, extending 30 to 35 feet in front of the runners, are attached to a single heavy cable, by which means the net or trawl is towed. These nets are operated in much the same manner as other trawls, except that a beam trawl is always set from the stern of the boat. They must be carefully weighted and balanced in order to insure setting on the bottom with the beam up.

The use of the term "beam trawler" is often confusing, particularly to a layman. It might be taken literally whenever mentioned in Portland, Oregon, or Seattle, Washington, whereas it would refer to an otter trawler if used in an East Coast port, such as Boston or Gloucester, Massachusetts. Despite the fact that beam trawlers have not been used in the North Atlantic fishery since shortly after the turn of the century, the fishermen here continue to use the term whenever referring to the large steel vessels, of the type which at one time employed the beam-trawl rig. These same fishermen further distinguish the size of a vessel by calling the smaller wooden boat class "draggers" although the gear used is an "otter trawl."

Gill Nets. There are two general types of gill nets employed in the commercial fisheries: anchor or bottom nets and floating or drifting nets. They are used in

practically every area of the country, from Alaska to the Gulf of Mexico, from Maine to California, as well as in the interior lake fisheries, and they account for a wide variety of fish.

It is interesting to note that approximately 65 per cent of all the fish caught in the Great Lakes fishery is taken with gill nets and that these nets would cover



(*Courtesy R. J. Ederer Co.*)

FIG. 13–15. North Atlantic gill netter. Diesel powered vessels set long strings of sink gill nets on the bottom, as shown, for cod, haddock and pollack.

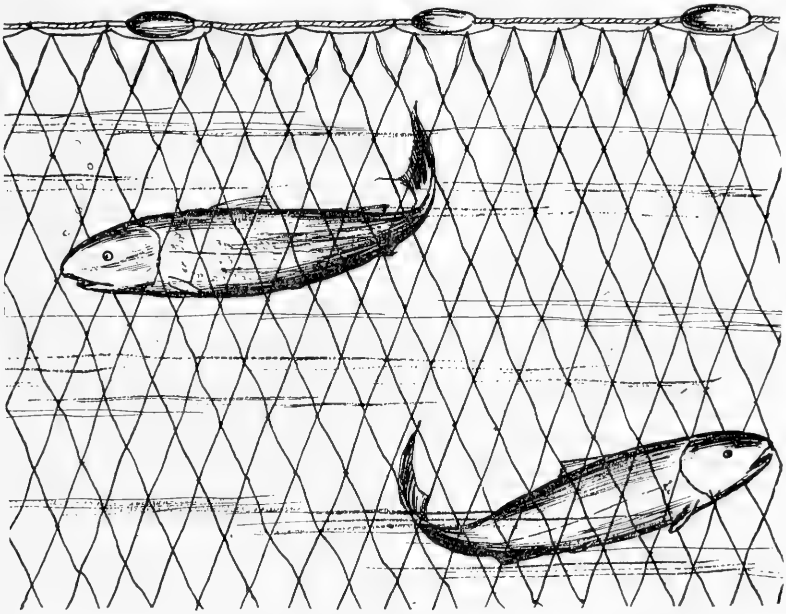
a distance of over 8,000 miles if joined together and stretched in a straight line.

Anchor-Gill Nets. In the Great Lakes the anchor-gill net is the most common type used. It is called "sink" or bottom net because it is sunk on the bottom, anchor net because it is held in position with small anchors. The meshes vary from 1⅝-inch to 5¼-inch mesh and can be roughly divided into two general classifications: "chub nets" and "trout nets." Sea Isle cotton is used in the construction of these nets because its greater strength permits finer sizes of twine to be used than if regular cotton twines were employed.

Sink-gill nets were first pioneered in the North Atlantic about 1918 by a few Lake Michigan fishermen, who settled in Gloucester, Massachusetts.

Drift-Gill Nets. Pelagic species of fish, such as mackerel, are caught in drift-gill nets. These nets are somewhat like sink-gill nets because they are rectangular in shape and are fished in strings. Because they float from the surface, suspended

to a depth of 25 feet, they are visible to the fish and must, therefore, be fished at night. The strings, or gangs of nets, are set in open waters; as single nets they are set in rivers and streams and allowed to drift under the watchful eyes of the



(Courtesy of R. J. Ederer Co.)

FIG. 13–16. Gill nets are designed to catch fish by the gills as they swim into the net, and hold or entangle them as they struggle to escape.

fishermen. Marker buoys, or sometimes lanterns, are attached to floats to permit the fishermen to follow the drift of the nets. Drift nets have larger floats on the top line than other gill nets and only enough leads on the foot line to hold the webbing down.

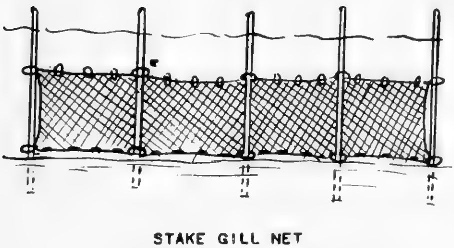


FIG. 13–17. Stake gill net. Portion driven into bottom shown by dotted lines.

Stake-Gill Nets. Quite similar in construction to drift-gill nets these nets are much shorter and shallower, averaging about 50 feet in length. They are generally set in eddies, one end tied to a stake or other stationary object, and the other anchored. In some instances both an anchor and stake are necessary; in either case marker buoys are set at each end.

Trammel Nets. Derived from gill nets trammel nets are sometimes called "tangle nets" since they check, hinder, and entrap. Three sheets of netting are suspended from a common cork line and attached to a common bottom, or lead, line. The middle net is of fine mesh, loosely hung, while the outer, guard nets, are usually 3 times the size of the center-net meshes. They are so constructed that a fish, striking from either side, passes through the large mesh and hits the small mesh netting, through which it cannot pass or is gilled. Its struggles cause the loose net to slip through one of the openings of the other large mesh webbing, forming a sack in which the fish is trapped.

From 10 to 50 of these nets constitute a string, the number set by one boat. Each net is about 40 fathoms long and 20 of these nets cover nearly a mile (4,800 feet). Wood or cork floats, 3 to 4 inches in diameter, are strung to the top line to keep the net upright in the water, and 2-ounce leads in pairs every 8 to 12 inches offset the pull of the corks and hold the net on the sea floor. When a net is set, the lead line rests on the bottom and the cork line holds the net in a vertical position under the surface.

The average string of nets is operated by crews of 3 to 6 men daily, weather permitting. They are anchored with stones or small boat anchors at the end of each 5 or 10 nets and buoyed with small kegs or identifying buoys at frequent intervals along the string.

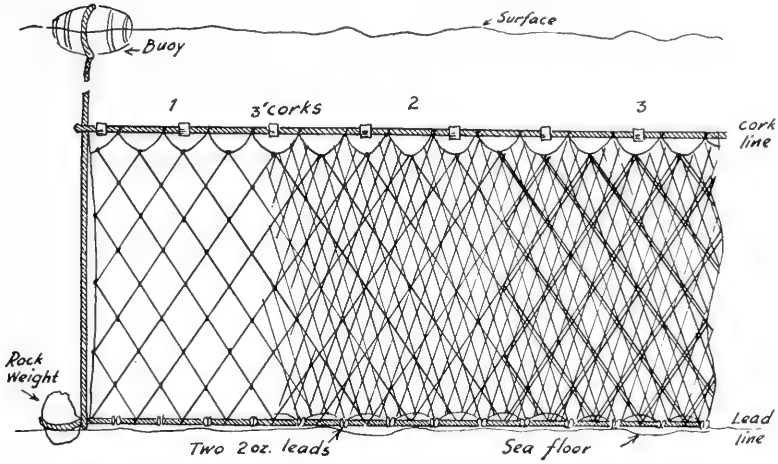
When a gang of nets is set, one end is put out with an anchor and buoy attached; then the nets are paid out as the boat travels at slow speed until the last end of the gang is anchored and a marking buoy attached. They are left in the water from 12 to 24 hours after which the fish are removed and the nets replaced. Every 2 or 3 days, or trips, the fishermen bring the nets ashore to dry and mend them. In some fisheries 3 gangs of nets are rotated daily; one is used in fishing, one is aboard the boat to be set, and the third is ashore drying.

Pound Nets, Traps, and Weirs. Enclosures formed by fences of stakes entwined with branches, placed in advantageous spots in streams, lakes, and along the shore of the sea, have long been employed in the fisheries. The openings are so placed that the natural course of the fish leads into the trap from which it is difficult to escape. Long leaders extending from the shore to the mouth of the trap serve as an additional aid in deflecting the fish into the trap. In principle they are similar to many animal traps.

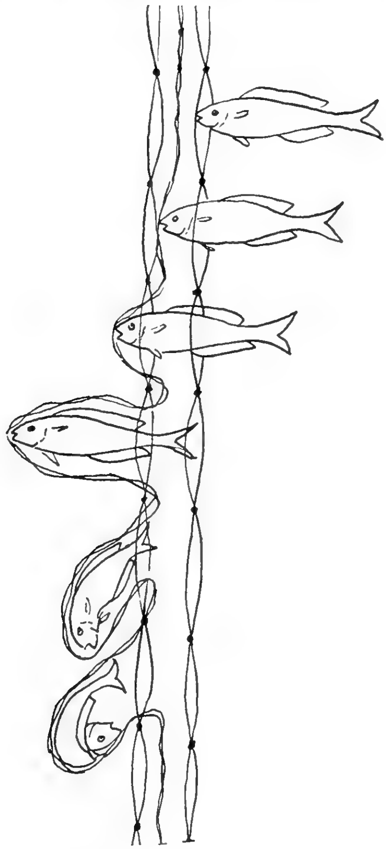
Trap-net fishing evolves from ancient stone and brush weirs used by primitive people. Large brush weirs are still common in the sardine-herring fishery of Maine. Such weirs are still practical where fishing and tide conditions are favorable. The 50-foot tides in the Bay of Fundy district afford opportunity to work on these weirs since they are nearly dry at low tide. In some instances natural estuaries or inlets along the shore are converted into natural pounds by simply stretching a stop net across the opening after the fish are inside.

There are numerous variations in the form and construction of this gear in use in American fisheries, but only a few of the more typical will be referred to in this chapter. Of these the weirs are the most primitive and will be described first.

Weirs. Fishermen usually put weirs at a point of land that extends out into the water for some distance, or in channels, frequently between islands, or ledges, where the tide is strong, to take advantage of the tendency of the fish to remain in the strong current.



(A)



(B)

FIG. 13–18. (A) Trammel set net, showing diagrammatically the three webs of netting. (1) single guard net; (2) guard mesh and small inner web; (3) both guard meshes with inner net between. (B) End view showing how fish are pocketed in small meshes of loose inner web.

The main body of the weir is a large circular or heart-shaped enclosure. This is formed by driving long, heavy posts into the bottom, with smaller posts set closely in between. Fine brush is then interwoven between these smaller posts, horizontally on the lower portion and vertically in the upper part, so that the latter is visible at high tide. A lead of brush extends from the shore to the mouth of the trap, made simply by driving heavy branches so closely together into the

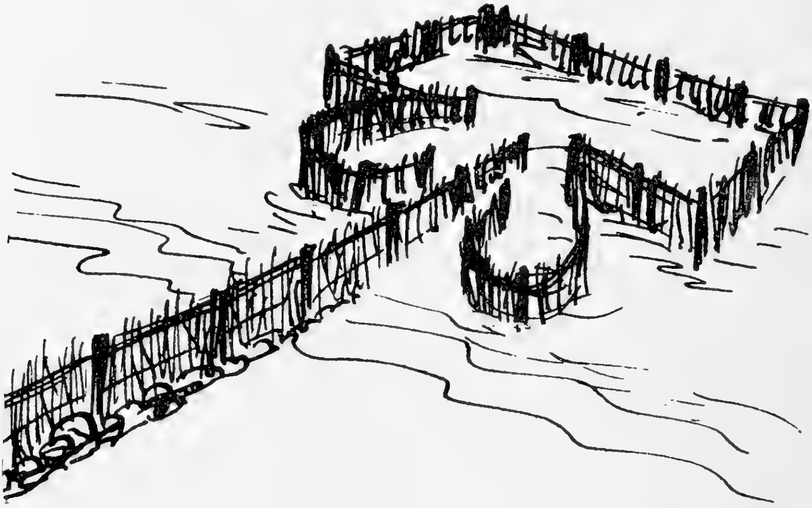


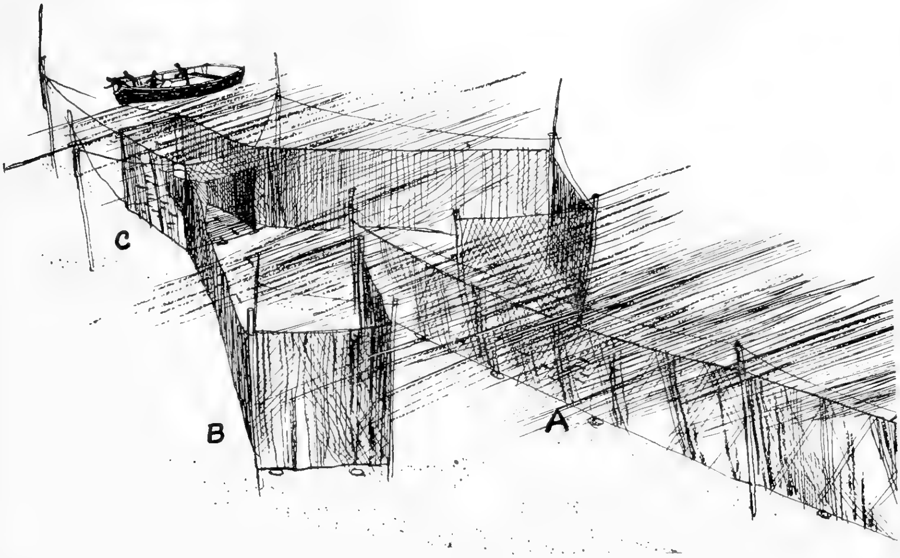
FIG. 13–19. Typical brush weir employed in the sardine fishery of Maine.

FIG. 13–20. Loading sardines into boat from a weir pocket along the Maine coast.

bottom as to form a wall. These leaders may be as much as 500 feet long and extend inside the mouth about 5 feet or more. The mouth is open wide enough on either side of the leader to permit entry with a dory. The heart or crib may be as much as 80 feet in diameter.

In recent years netting has to a large extent replaced the brush formerly used in the heart of these weirs, but use of brush leaders has continued. After the dory has entered the weir, the mouth is closed by dropping a net; this prevents the possibility of fish escaping. In some of the larger weirs a small hand seine is used to capture the fish. In others the trap bottom is raised by means of pulleys and the fish are herded into a section known as the brailing piece, made of somewhat heavier twine. The fish are then, in either case, dipped or brailed into the dory and taken directly to the packing plant, or are transferred to a sardine transport.

Pound Nets or Traps. In its simplest form a pound net consists of three parts: (1) the leader, extending from the shore or shallow water to the (2) heart or



(*Courtesy R. J. Ederer Co.*)

Fig. 13–21. Ordinary trap net showing leader (A), heart (B), and crib or pot (C).

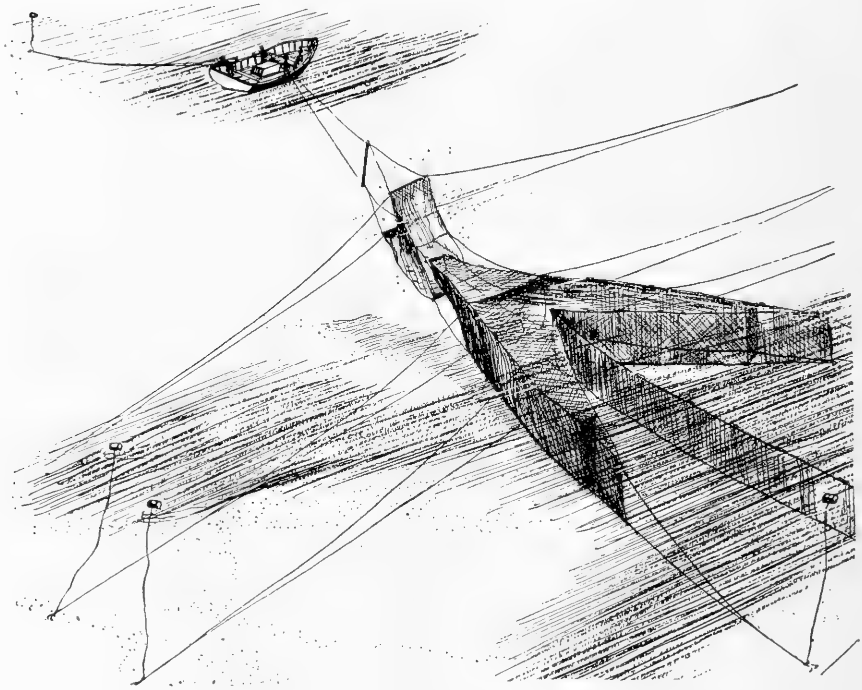
wings, a heart-shaped enclosure which deflects the fish into (3) the crib. The crib or pot is usually rectangular, and it is here that the fish are captured. The term "pound," as used in a pound net, refers to the impounding of the fish within an enclosure.

Leaders up to 800 feet long supported by poles, driven by pile drivers, extend offshore to the entrance of the heart, which is the first stopping place of the fish. The heart, a netting enclosure, is about 72 feet across. Entrance into the crib is gained by means of a 14-foot open space, called the gate, which is situated directly in the center. Cribs are as a rule considerably larger than hearts. Oval-shaped, they are as much as 80 to 100 feet across and up to 200 feet long and consist of

small mesh netting supported by firmly attached 65-foot poles. This section has a net bottom secured to the sides. After the bottom has been raised, the fish are brailed directly from the crib into specially designed tenders.

The heart or crib of this type of pound net, like a weir, has no cover since it is set at depths permitting the top rim to be exposed at high tide.

Submarine Traps. Deep-water traps are found principally in the Great Lakes. They were designed to fit the particular conditions existing there. Their effective-



(Courtesy R. J. Ederer Co.)

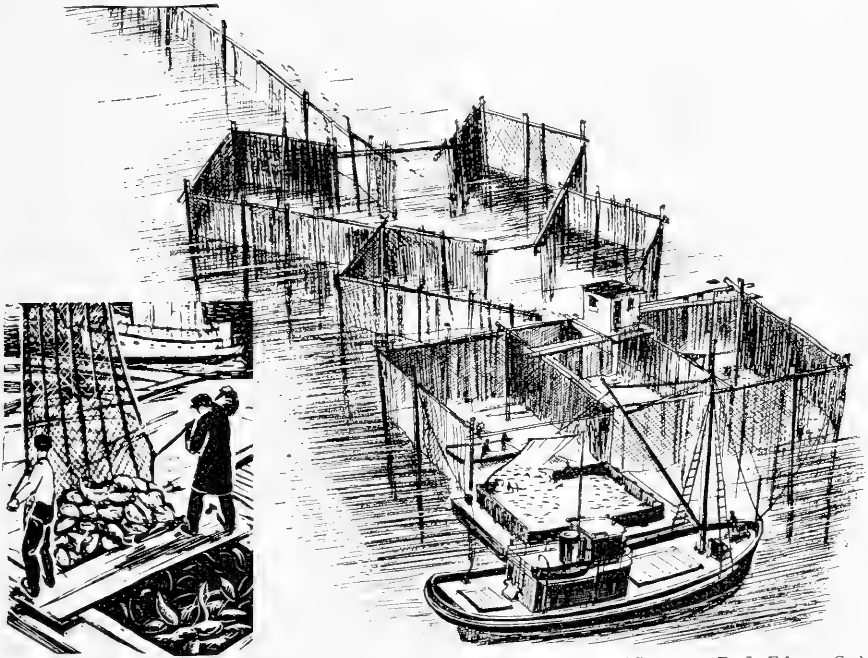
FIG. 13–22. Trap boat raising pot of Great Lake submarine trap to surface.

ness depends largely upon the several anchor lines that hold them in place since they must be held taut and straight to keep the tunnels open.

Submarine traps, as they are generally known, have rather short leaders because they are set closely together in long rows. A pair of wings, spread V-shaped and usually hooded, aid in directing the fish into the pot, which has two inside tunnels and is completely enclosed. In removing the fish from the pot the long anchor lines running from the tail end are lifted to the surface by means of a buoy line. The vertical spreader in front is loosened and as the boat works closer the tunnel of the pot is brought aboard. The drawstring is then loosened and the fish removed.

Floating Traps. The Alaska floating trap, used in the salmon fisheries, is constructed of logs which are solidly braced and bolted together. It is anchored offshore and held in place by several large anchors capable of holding under heavy

strain. The leader webbing is hung from a long cable running from the shore to the trap and weighted down to the bottom. The netting in the trap proper is attached to the log framework. These traps, following the usual design, have one or more hearts on the side of the leader exposed to the prevailing winds or currents so that more fish will be effectively directed into the inner chamber or pocket. These are located at the offshore end of the leader, which is about 1000 feet out from the shoreline.



(Courtesy R. J. Ederer Co.)

FIG. 13–23. Cannery tender brailing salmon into scow from an Alaska salmon set trap. Detail of brailer shown in insert.

These heavy traps, including the stationary type which is almost identical except for the fact that it is held in place by pilings driven into the ocean floor, are unloaded by means of spillers. The ordinary trap net used in other fisheries is usually unloaded by lifting the entire bottom web of the trap from which the fish are brailed into the tenders. In the salmon fishery the spillers are apronlike pieces of heavy netting (usually Manila) about 12 feet wide and 20 feet or more long. The inboard edge is secured to the barge rail, the outer edge to a beam weighted with chains. This is lowered into the bottom of the trap by means of tackle operated from a boom on the barge. As the fish swim above this webbing, it is raised, scooping them up from a horizontal to a vertical position and spilling them into the hold. This operation is repeated until all the fish have been removed.

Reef Nets. Reef nets, as the name indicates, are set on reefs. They are used exclusively in the shore fisheries and are similar in appearance to a small pound net without a heart, but are less substantially constructed. The reef acts as a leader

in addition to the one made of netting. At the outer (offshore) end of the netting is a pound of four sides of netting where the fish are held. The inshore side of this pot or pound is let down when the net is fishing. When quantities of fish are observed moving toward the pot, the fishermen sometimes follow in small dories and frighten the fish into entering it. Two men stationed at the opening pull up the front sheet of netting, thus trapping the fish. The bottom of the pound is then lifted and the fish removed with dip nets.

Fyke Nets. This form of gear is largely used in fresh-water fisheries, usually in rivers and streams, for the capture of such species as carp, catfish, yellow perch,

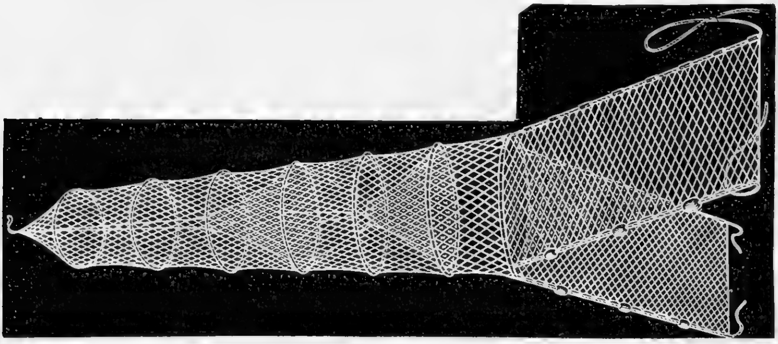


Fig. 13–24. Fyke net showing hoops supporting webbing and funnels through which fish work their way and become trapped.

suckers, etc. The fyke net is a long bag of netting, shaped like a funnel and distended by a series of wooden hoops diminishing in size from 6 or 8 feet in diameter at the mouth to 2 feet or less near the pocket. The number of hoops varies from 2 to 15, but averages 6. The netting is of 4- or 5-inch meshes at the open end, diminishing to 1 or 2 inches at the bag end, which is made of fine twine. These nets average about 10 or 12 feet in total length and are collapsible, making them easy to store and handle.

Cast Nets. This type of gear is popular throughout the Gulf States and on the Pacific Coast, where they are used commercially in shallow waters along beaches and river banks. A wide variety of fish are taken with cast nets and at one time they were an important item of gear in the shrimp fishery. This is one of the few forms of gear used in greater numbers by sportsmen than by commercial fishermen.

Cast nets are circular in shape when spread flat and average 12 to 18 feet in diameter. Numerous leads are attached to the circumference and small cords, radiating from the control line and passing through the center ring, are secured to this lead line. These nets must be knit by hand as their construction is complicated by the fact that meshes must be added in almost every row to achieve the proper circular shape. Linen twine, similar to those in gill nets, size $^{35}/_{3}$, or its equivalent in cotton, are used, the meshes varying from 1½ to 3 inches.

Considerable skill is required to handle effectively a cast net since the netting must be draped over one arm and thrown in such a manner that it will spread out in a flat circle when it hits the water. Before being thrown the control cord is usually secured to the wrist of the fisherman. When the net lands in the water,

the weight of the leads carry them to the bottom forming an inverted bowl of netting over the fish. As the control line is drawn up the lead line is puckered together trapping the fish. It is then hauled ashore and the fish removed.

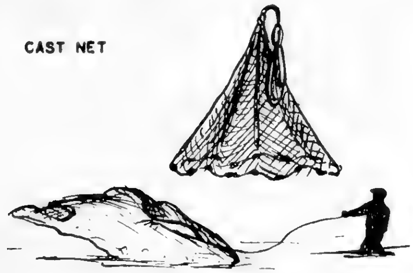


FIG. 13–25. Cast net and manner of throwing.

Fish Lines. There are two general classes of lines used in the fisheries: (1) hand lines, the common hook and line, which are set or trolled, and (2) set lines, or trawl lines, from which a series of hooks are suspended. Both are baited and hand-operated.

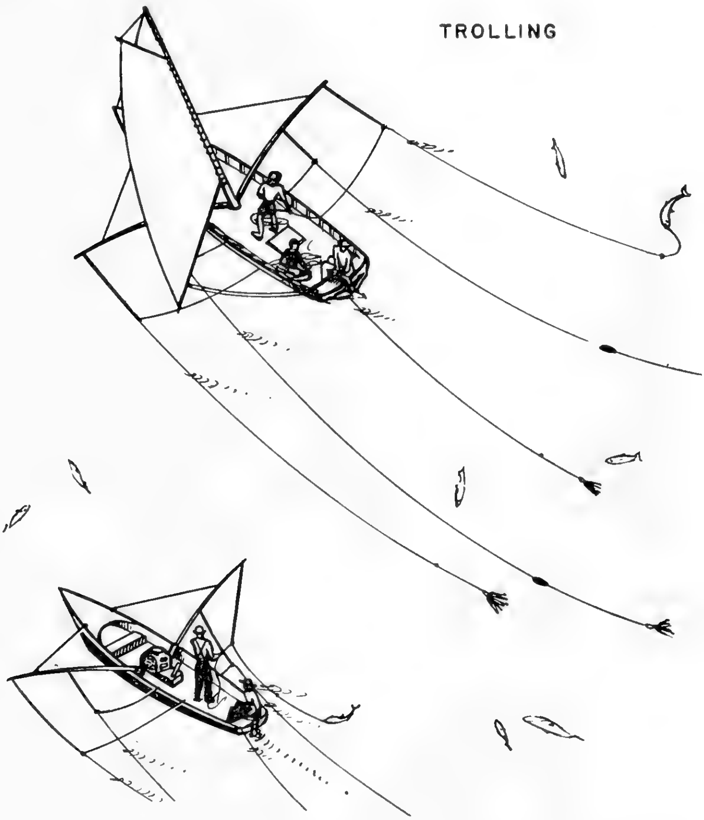


FIG. 13–26. Trolling with outriggers, an economical small boat operation.

Hand Lines. This form of gear is commercially important in the red snapper fishery of the Gulf of Mexico and in the salmon and tuna fisheries of the West Coast. At one time they were of importance in the New England bank fisheries, but were supplanted by the trawl-line fishery about 1920.

In the red snapper fishery tarred cotton lines about 60 fathoms in length, with 2 hooks at the end and a 2-pound lead sinker placed about 6 feet above, are set from the deck of the fishing schooner. The vessel is hove to and the lines set out when fish are located.

When the lines are trailed behind the boat without the weight, they are called troll lines. Sometimes poles hold them above deck level. Usually 2 or more poles of different lengths are set in sockets on each side of the boat while 2 lines are

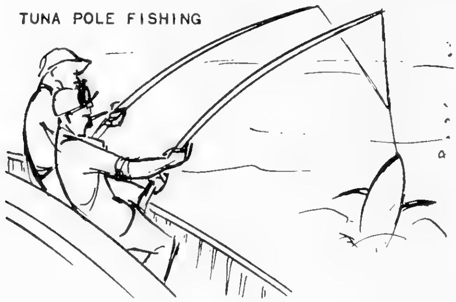


FIG. 13–27. Two pole method of hauling in heavy tuna in Pacific fishery.

set from the stern. The lines are forked at the end, providing for 2 hooks, and are held apart by wire spreaders. Nickel spoons are popular although in some instances herring is used for bait.

In the California tuna and albacore fisheries the fish are sometimes trolled; when a strike is made, quantities of small live fish, such as anchovies or sardines, are thrown overboard to attract and hold the tuna near the boat. Short lines with barbless hooks attached to stout bamboo poles are then thrown into the school. The fish bite readily and are lifted straight out of the water by sheer strength and shaken from the hook. Individual fish range from 25 to as much as 300 pounds. There is little sport and much hard work involved in this type of fishing, attested by the fact that a fisherman can catch as much as a half ton of fish per day with such a rig.

Trawl Lines. Trawl lines were once used almost wholly in fishing for ground fish (i.e., cod, haddock, hake, cusk, halibut, rockfish, etc.). In the New England fisheries this method has been supplanted by otter trawls during the past two decades. These vessels, which used to carry 12 to 16 dories, each supplied with 4 to 6 tubs of trawl, a tub representing 500 hooks, or a total of 35,000 hooks, were operated by crews of as many as 24 men. Most of them have now been converted to otter trawling. Although there are a number of small boats still used, the fishing is done from the decks, rather than from dories, and consequently fewer lines and men are engaged.

In the halibut fishery off the northwest coast this form of fishing continues. Here the lines are set in considerable numbers over the stern of the vessel and are operated with small power gurdies or winches from the deck. These lines, called "skates," were, until recent years, employed in the halibut fishery of New England.

Seven or eight lines, approximately 225 feet long, fastened end to end, constitute a skate, about 1600 feet long. Gangions, which are lines 5 or 6 feet long with a hook at the free end, are attached to the main line every 9 feet. Frozen herring is used as bait. Twelve to fourteen dories, 1 or 2 men in each, set out about a mile apart on arrival at the fishing grounds and cover an estimated 36 square miles or more daily.

In recent years a sizable number of halibut fishermen on the West Coast have changed from the usual hemp trawl lines to stainless steel wire. During 1949,

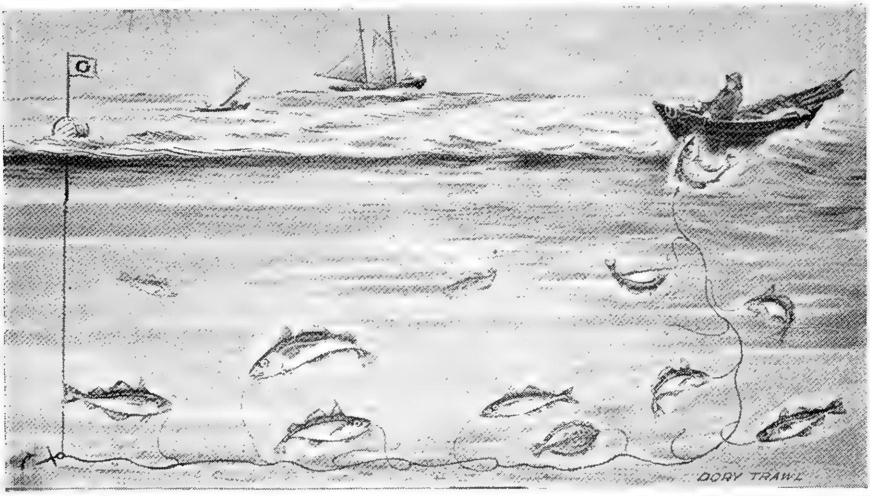


Fig. 13–28. Illustrating trawl line, hand operated and set from dory.

when there was an estimated 14,500 skates of halibut gear in operation, replacements during the season approximated about one-third the total, due to hang-ups, deterioration, etc. This annual expense, together with the rising cost of gear, necessitated the use of wire lines. It has been found that the use of wire requires fewer men to work the same amount of gear, that there is less frequent replacement, and that the gear is more easily recovered if hung-up on the bottom. The use of wire also permits the boats to cover a wider area since the gangions are detachable and can be spaced farther apart with little effort.

These lines are $\frac{5}{64}$- or $\frac{3}{32}$-inch diameter, "non-kinking" stainless steel of 3×7 construction for the ground and buoy lines respectively, while the gangions are of single strand wire varying in length with the height of the vessel's rail. Gangions are attached to the ground line by means of a stainless steel snap of sufficient size to fit a man's hand, which prevents the wire from cutting him.

The variability of hook spacing at any desired distance by simply snapping the gangions onto the ground line and the speed at which the gear can be paid out and hauled back are important features of this new rig. Each skate of wire line is approximately 200 fathoms in length. Reels have been developed for this fishery holding 1200 fathoms of wire each—in 200 fathom skates—with proper linkage between the separate skates of line. Such a reel weighs only 80 pounds fully loaded, so that a vessel carrying 10 reels can run 60 skates of gear with a total

weight of about 800 pounds. These reels of cast brass are mountable on either end of a Monel metal shaft fitted on a galvanized base machine standing 33 inches high and 42 inches wide. This head, with reels, can be swiveled to allow the line to run out straight over the stern and then turn to reel in over the starboard rail without forcing an extra bend in the line as it comes in. A clutch and brake is fitted to each spool for greater operating efficiency. A three-speed transmission permits a selection of reel speeds as the gear piles upon the spool and requires only about one horsepower to run. The drive can be attached to existing deck shafting or a shaft run direct from the engine.

The method of hooking the gangions on as the line goes out is relatively simple as well as safe. Baited gangions are laid in a box with all the hooks at one end. While one man controls the wire speed, another, standing beside him and facing the line, grasps the hook point up with one hand and the snap with the other. As the lines moves by, he simply hooks the snap on with his right hand and swings the hook away from him with his left hand, while at the same time clearing to pick up the next gangion. In hauling back the comparatively short gangions enable the man tending the roller to gaff fish without having to reach over the rail or draw up slack as he brings the fish over the rail into the checkers.

This type of gear offers particular advantages in line trolling in which it is still in an experimental stage; where only two lines are run, it is a simple matter to set one line off each reel with the lines controlled by the clutch and brake built into the machine in one unit. This rig makes it possible to operate the gear faster and more easily with less crew, or more gear if the present crew members are employed.

Eel Pots. The common eel is found in brackish waters along the Atlantic Coast, the commercial fishery extending from Maine to North Carolina. Average annual catches amount to one million pounds, valued at approximately $100,000.00.

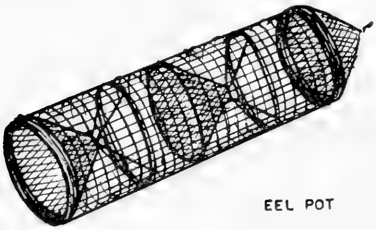


FIG. 13–29. Eel pot, showing inner funnels.

Gear employed in the taking of eels commercially varies to a considerable degree since any apparatus, such as spears, hook and line, or gear capable of catching or holding fish, may be used. However, traps or pots are predominant in this field. There are several types of traps, but their features are almost identical, as will be noted.

Galvanized wire-mesh pots, in the form of a cylinder 30 inches long by 10 inches in diameter, are most popular in the North Atlantic area. The meshes are ½-inch square, 16-gauge galvanized wire, secured to iron rings. One end has a cover, held in place by a clasp to permit the removal of the eels after they enter. Entrance is gained through a funnel made of cotton netting, another inside funnel prevents the fish from escaping. These pots are baited and set in rows, each having a Manila hauling line which is buoyed. Fishing is usually conducted in

5 to 25 feet of water and fishermen operate on an average of 150 pots per man. Such pots weigh about 35 pounds each, cost relatively little, and can be expected to last 3 to 5 years.

Eel pots, typical of the Middle Atlantic States, are made of oak splints woven in basket-weave design. They are also cylindrical, 8 inches in diameter, 24 inches long, but taper to 6 inches at the mouth or funnel end. This funnel is also made of the same material and extends inside the pot two-thirds its length, having an opening only 2 inches in diameter at the inside end. Since the pots are light in weight, one man can operate as many as 300. These are set in strings of 25, which are attached to 10-foot gangions on a long Manila trawl line. When "river pirates" molest the traps, fishermen find it expedient to anchor both ends of the lines rather than to buoy them, after first ascertaining their position by taking a land fix bearing.

Electronic Marine Devices in Fisheries

A foreign visitor to United States' fisheries, in almost any section of the country, will undoubtedly be attracted by the numerous types, applications, and wide variety of electronic instruments aboard the larger tonnage vessels for locating subsurface schools of fish. He will also notice fishermen who continue to catch fish with the traditional hook and line, taking one fish at a time. However, since each method produces for a definite market, there is no conflict. The larger vessel catches fish for the modern "production line" fish-processing houses. The line fishermen produce for the local fish market or often sell directly to the consumer.

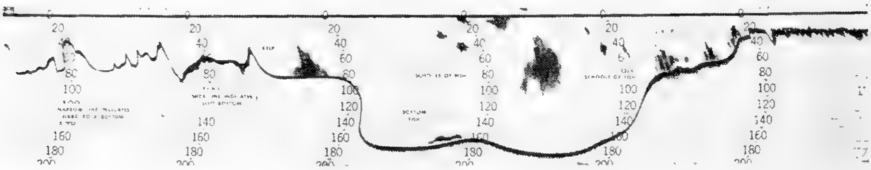
Certain scientific precision instruments are today practically standard equipment aboard modern fishing vessels. "Ship-to-ship" and "ship-to-shore" radio telephones, radio direction finders, and subsonic depth recorders were the first to attain popularity. Short-wave radio telephones, with which most of us are familiar, were first to appear about 1929. Practically every registered vessel in the fisheries is now equipped with at least one of these items, especially the telephones and direction finders.

During recent years electronic subsurface detectors were successfully developed, and many of these have been adapted for use in the marine fisheries. A few of the more highly specialized instruments, particularly radar and sonar, are already in use in fishery operations. They not only facilitate safer navigation, but also save time in searching for schools of fish. Considerable promise is held for their future.

Electronic Depth Recorders. Shortly after the widespread installation of radio telephones on practically all of the offshore fishing vessels, the automatic depth recorder made its appearance about 1930.

The depth recorder sends out a signal in the form of an electrical impulse from a transmitting oscillator attached to the hull to the bottom or the floor of the ocean. The echo is picked up on the receiving oscillator and is amplified and recorded. In the earlier type a red light flashed beside a number on the dial signifying the depth in fathoms. More recently, as a result of research during the past World War, this instrument has been improved to such a degree that the depth of water is shown as a heavy black line on a paper graph. It is so sensitive that a school of fish beneath the ship can be detected as a second, usually lighter, line above the true bottom. Since this is on a paper graph, it becomes a permanent record, available for use at any time.

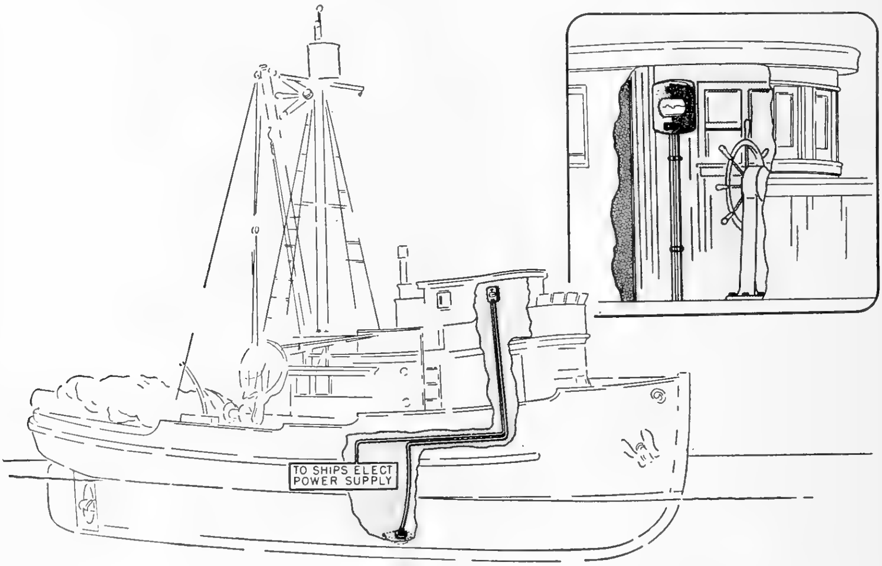
Thus, it is now as easy for a fisherman or mariner to "get the lay" of the ocean floor as it is for him to read a newspaper; he merely looks into a window to see the contour and depth. Moreover, he needs no special training to use this depth recorder to locate fishing banks and schools of fish.



(*Courtesy Bendix Aviation Corp.*)

FIG. 13–30. Composite chart made from actual recordings by fishermen showing various conditions indicated by a supersonic depth recorder.

Because these instruments completely eliminate the old time-consuming method of taking soundings by hand, more often than not inaccurate, especially in rough weather, they are widely used today.



(*Courtesy Bendix Aviation Corp.*)

FIG. 13–31. Cutaway view showing installations of supersonic depth recorder in wheel house and location of transducer, which sends and receives supersonic signals in hull. The transducer can be mounted inboard through a sea chest or externally.

Sonar—Submarine Radar. Sonar can be used not only by mariners in avoiding submerged reefs, wrecks, and mines, but also by fishermen in locating fishing banks and bodies (schools) of fish and even in distinguishing the species by their grunting, purring, croaking, or drumming sounds. Although submarine sound-detecting devices are not entirely new, developments during the past decade have finally led to its practical use today in safer navigation and as a possible aid to more productive fishing.

The variety of sonar devices is startling, and more are being developed. Among these are a low cost fish detector for the commercial fishermen. Sonar machines are reported to be already in use on a few commercial fishing vessels at West Coast ports.

Although a few specially designed sonar ranging devices used by the Navy revealed the presence of submarines more than 6 miles away, the average machine has a lesser range.

Sonar equipment costing less than a new net are now in the final stages of development and are expected to pay for themselves, not only by helping to locate fish, but also by revealing the rocks and wrecks on which costly nets are all too often torn or lost.

The echo-ranger is called sonar in this country and asdic in Great Britain. It should not be confused with radar. The echo principle is the same, but wave frequencies used in radar cannot be used under water.

Radar. Radar might be referred to as one of the greatest marine surface-searching aids ever to be developed. The perfection and practical applications of this micro-wave navigating detector were hastened by 1941 war developments. American ingenuity, intensified by the necessity of an all-out war effort, made it possible to furnish the Navy with these "eyes" with which to work in detecting the presence of an obscure enemy at sea or in the air.

As a navigational aid radar is now rapidly growing in importance, not only in our merchant marine fleet, but in the commercial fisheries as well. There are already a few installations aboard tuna clippers.

Loran (Long-range Navigation). Loran is an electronic system for accurately determining the geographical position of a ship in any kind of weather. It is comparable to the telephone in that it enables the navigator to check his position without leaving the chart room. Fixes are obtained from transmitting stations in from 2 to 6 minutes, at distances of 750 nautical miles by day to 1400 by night.

The loran system of navigation, already installed on many fishing vessels, makes use of special transmitting stations on shore. It differs from radar in that no transmission takes place and no echo is received. Unlike the radio direction finders loran measures the time, rather than the direction, of arrival of the signals.

Transmitting stations on both coasts operate in pairs 200 to 400 miles apart, designated as master and slave stations. It is relatively easy to operate loran equipment since no knowledge of electronics is necessary.

The master station starts the cycle of transmission by sending out a pulse which reaches the slave station and at the same moment any loran receiver in its range. This is repeated constantly 24 hours a day. Since each transmitting, or master, station is identified by its radio frequency channel, a positive "fix" shows the exact position of the vessel when two have been intercepted.

Automatic Steering Devices and Suction Pumps. Additional equipment, developed within the past two decades and growing in popularity in the commercial fisheries, should include the mention of automatic steering devices and suction pumps for unloading fish cargoes.

"Robot pilots," as automatic steering devices are sometimes called, operate electrically without deviation from any fixed course on which it is set. Although they must be set manually whenever changes in bearings are necessary, they have

still proven successful, particularly in smooth seas, since it allows the man who would otherwise have to be at the wheel to work on deck.

Although the use of suction pumps requires that the fish in the hold be floated, the success of this method of unloading, particularly in the sardine-herring fishery, has recently led to its adoption for use at sea for unloading seines directly into the vessel.

Furthermore, a method for weighing the fish in conjunction with this equipment has been reported, which eliminates any handling and considerable loss of time. A few are already in use in the industry.

Electrical Fishing Device. In connection with the developments of the suction pump and its recent adaption at sea to remove fish from purse seines, there were numerous speculative theories as to the possibility of simply sucking the fish directly into a boat from the open sea without the aid of a net. Such an idea, fantastic as it might appear, seems probable since the recent invention of a German electrical fishing device, which has been developed to such a stage that actual tests at sea have been planned. It has been pointed out that by placing two electrodes into a body of water and varying the positive voltage on the "anode" between 0.5 and 1.5 volts the fish within the field of the cathode and anode are made to point toward the anode. The action of the varying electrical field along the spine causes the tail muscles to alternately contract and relax, moving the fish toward the anode. The usual commercial species of fish seem to react within this voltage range without harmful effects. Since small fish are not affected, it shows promise of being one of the most conservative ways of fishing yet developed.

During these same trial tests arrangements have been made for an American firm to set up a large size fish-suction pump. As the fish move in toward the anode, they are drawn directly into the hold of the vessel, eliminating the use of conventional fishing gear of any sort.

Economically, the advantages seem equally important as the rest of the invention because the electrical method provides a greater certainty of successful catch by covering a larger fishing field in a shorter fishing time. New areas, heretofore inaccessible, can be exploited with fewer crew members and the trips shortened by several days. It is further estimated that the cost of the electrical equipment and its installation amounts to only 3 to 5 per cent of the value of a medium-sized vessel. This invention, if successful, will revolutionize commercial fishing.

Preservation and Care of Fish Netting

Although the life of a net may be extended by frequent mending, which is diligently practiced, mending does not entirely overcome the impaired efficiency and dependability of an old net. For this reason, and also because the additional disintegrating factors caused by exposure to sunlight, air, and water further weaken the net, the use of preservatives is necessary.

The period of time in which a single net may be used, discounting the possibility of total loss by storms, etc., varies in the different fisheries from a few weeks to a few years. With the application of net preservatives the average life of any net is one year more or less. Because fishermen spend nearly 25 million dollars annually for the replacement of nets, a figure representing about 8 per cent of

the amount they receive for their fishery products, the means of increasing the life of netting is a matter of paramount importance.

The use of various preservatives which date back many centuries continues today for the following reasons:

1. Protection against mechanical wear and tear, resulting from the rubbing (abrasion) of the threads against one another, the floats and leads, the sides of the boat, the drag on the ocean floor, etc.
2. Protection against the action of microorganisms.
3. Protection against oxidation, resulting from the storage of the nets while wet or covered with fish oils and blood and slime.
4. Protection against fiber-tendering effects when exposed in strong sunlight after cleaning or during drying periods.

Cutching and so-called "tanning" of nets is among the oldest known methods of preservation. Cutch, also known as "catechu" and "querbracho," is a general term applied to the boiled down, aqueous extract of the bark, wood, or leaves of various trees or plants, ranging from such tropical forms as the acacia tree of India to the birch, hemlock, or pine of temperate climates. These materials in extract or dry bark form continue to be used today, but are far less popular than formerly. The general conclusion appears to be that such treatments are not very efficient. The protective action is of such short duration that frequent retreatments, involving costly labor and time, are necessary.

The use of tar for the preservation of nets dates back almost as far as the use of cutches. Products such as coal tar, pine tar (wood tar), and creosote have been widely used for many years. Although still in use today they are being replaced by modern chemical preparations.

Tar was originally applied to nets because its action tends to glue the fibers together, thereby increasing their strength as well as waterproofing them to some extent. However, the resulting stiffness and the increase in weight were unfavorable factors. The rigidity of the net caused it to wear out mechanically; after several applications the net often gives way at the knots. Because the tar must be heated to relatively high temperatures, the nets were often burned or tendered (weakened). Thinners are sometimes added to overcome the necessity for heating, but this is not too satisfactory. The use of tar is also attended by certain dangers to those who come in contact with it, particularly the poisoning from "tar dust" which collects on dried tarred netting during winter storage.

Early scientific studies showed that the deterioration of a net was due principally to the fact that microorganisms consume the cellulose which constitutes 95 per cent of the fibers. On this theory metallic compounds were first introduced in the form of copper sulfate, better known as "bluestone." After widespread use, both here and in Europe, it was discovered in 1930 that bluestoning had no prolonged effect, although it did act as a deterrant to bacterial growth if used often enough.

It was at about this time that copper oleate and copper naphthenate were introduced since they were found to be more effective as preservatives. However, these products tended to leach out rather quickly. In recent years copper naphthenate has almost entirely superseded copper oleate as it is more stable and better adapted to marine uses. It is now the principal toxic ingredient in most of the net preservatives. That such products are far from being perfect is best

illustrated by the fact that since 1945 there have been literally hundreds of new fish-net preservatives on the market.

During World War II, due to the great scarcity of netting fibers, intensive studies were made to find preservatives to lengthen the life of the precious fibers. It was decided that an outstanding net preservative must fulfill certain definite qualifications in order to combat or withstand the effects of salt- and fresh-water immersions, exposure in air contaminated with industrial fumes, and prolonged

FIG. 13–32. Reeling sink gill nets to dry, a practice followed in the Gloucester (Mass.) and Great Lake fisheries.

exposure in strong sunlight. The following factors summarize the points involved in selecting an ideal net preservative: (1) It should completely penetrate the fibers, (2) should not affect the flexibility of the net, (3) should retard marine growths, (4) should prevent the growth of microorganisms, (5) should add strength without undue weight, (6) should be of a color acceptable to fishermen, (7) should not cause knot slippage, (8) should prevent oxidation and fiber tendering in sunlight or storage, (9) should be applied easily, (10) should noticeably increase the life of the net, and should enable the net to catch fish after treatment.

Preservatives cannot protect nets from damage due to neglect, carelessness and a lack of cleanliness. Since all gear is more or less contaminated with slime and other matter from the ocean or vessel after it is fished, attention should be given to cleansing or neutralizing as quickly as possible. Washing with fresh sea water or sprinkling with generous quantities of coarse salt are methods most generally adopted and are quite effective. Frequent washing and drying whenever possible is highly recommended as it has proven to be the simplest means of maintaining the strength of a net.

Care should be taken to dry the nets in a shaded area as prolonged exposure to sunlight is quite injurious. During the offseason storage period the nets should be loosely suspended in well-ventilated shelters. When thrown in piles heaped on the floor, they are extremely subject to mildew attacks.

At the present rate of technical advancement it would appear that a net preservative which will fulfill the requirements of both the fishermen and scientists

will be produced in the near future. Meanwhile, to summarize the present status of this problem, it can be fairly stated that considerable progress has been made, particularly during the past decade, and that this advancement can be largely attributed to the cooperation of the fishermen.

Gear of Foreign Fisheries

Canadian fishing methods and the types of gear now employed in the commercial fisheries have kept pace with improvements in the gear used in the United States during the past two decades. The result is that the gear of the two countries are quite similar. In Great Britain the variety and form of the fishing gear now parallel United States usage.

In general the types of fishing gear which account for the greatest production in the northern European fisheries are largely otter trawls, drift-gill nets, sweep nets (modified seines), trawl and hand lines, haul nets, and purse seines.

In the South American republics the fishing gear has been improved through the introduction of power vessels and the discovery of new fishery resources. This has resulted largely from the assistance given these countries by the Office of the Coordinator of Inter-American Affairs and by the trained fishery technologists sent to these countries to survey the natural resources. Native fishermen who were shown the various types of gear used for catching the most abundant species in these coastal waters were soon profiting from their observations. Work along these lines, conducted in Venezuela, Colombia, Panama, Costa Rica, Nicaragua, Honduras, British Honduras, El Salvador, Guatemala, Cuba, Haiti, the Dominican Republic, and the British West Indies during 1942, is contained in a report titled, "The Fisheries and Fishery Resources of the Caribbean Area." The recommendations resulting from this survey have in many instances already been carried out, and are accountable for greater employment and expanded commercial fisheries.

Work of a similar nature has been conducted in Peru and Chile and has contributed to the recent expansion of these fisheries through the adoption of such gear as trawl nets, trammel and gill nets, seines, etc. The United States has main-

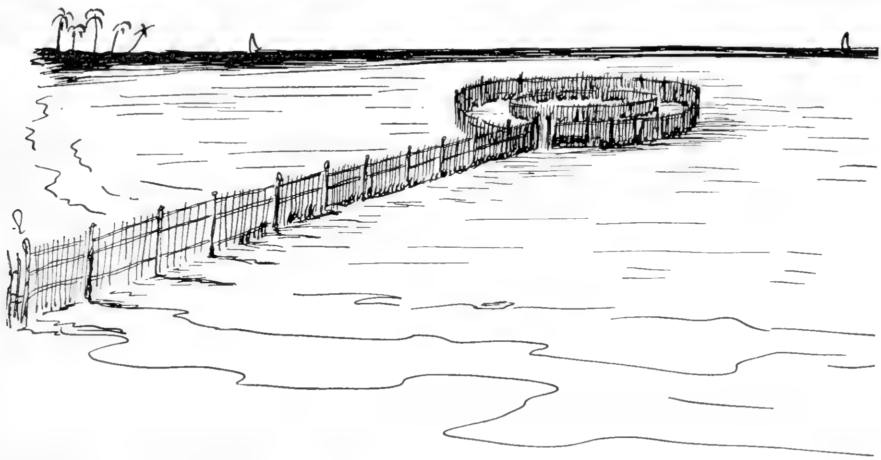


Fig. 13–33. Brazilian fish weir closely resembling those used in Maine sardine fisheries.

tained a full time fishery mission in Mexico since 1939, with the result that there has been, and continues to be, a tremendous expansion of the fisheries on both the east and west coasts of Mexico. The extensive exports of Mexican fishery products into the United States have resulted in greatly increasing United States

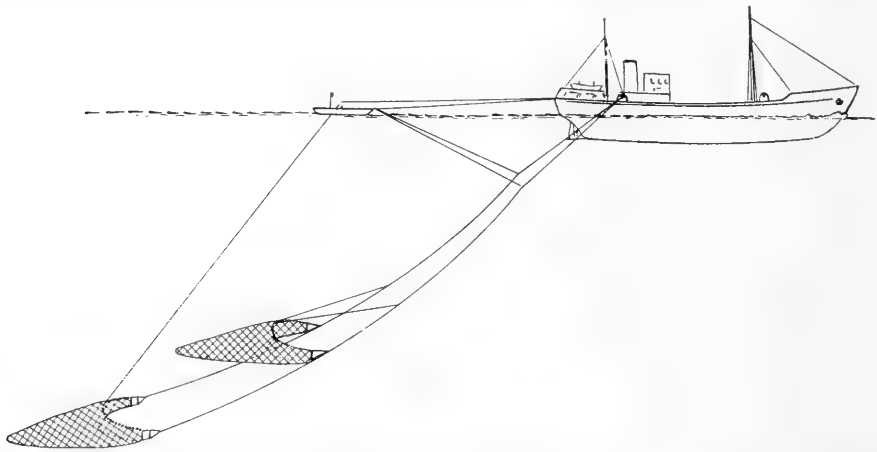


FIG. 13–34. New type floating trawl (Schatz) invented in British East Africa. Dispensing with doors saves power and increases efficiency.

exports to Mexico of such items as vessels, nets and netting, cordage, engines, refrigeration, and packaging equipment. Mexico is to a large extent dependent upon outside sources for such equipment.

Fishing gear in these Central and Latin American countries include weirs, gill and trammel nets, otter and shrimp trawls, haul seines, cast nets, purse seines,

FIG. 13–35. Typical outrigger canoe (dug-out type) widely used in South Pacific fisheries.

trot, hand and troll lines, and pound or trap nets. They are made of cotton or other native fibers knitted by hand or machine, and in general are nearly as good as United States nets. In contrast one may see the natives in remote coastal villages catching their fish by such primitive methods as bow and arrow, hand-carved spears, hooks made of shells, etc. Although the use of poisons and dynamite are occasionally resorted to, such methods are now illegal in most of these countries.

Improvements in the fisheries of the Mediterranean area, particularly in Spain, France, Italy, and Greece, have been brought about within the past 15 years by the introduction of powered vessels; this has permitted a greater exploitation of the natural resources. The expansion of the offshore fisheries can be largely attributed to the use of otter trawls and purse seines although hand lines, gill nets, trap nets, etc., are widely used.

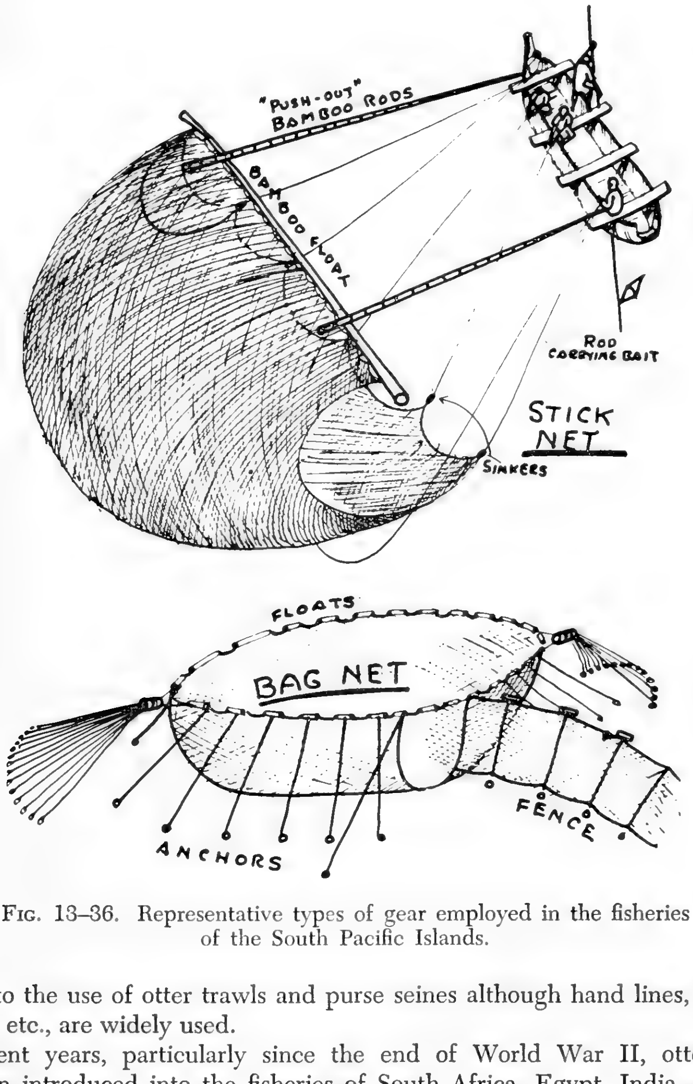


FIG. 13–36. Representative types of gear employed in the fisheries of the South Pacific Islands.

In recent years, particularly since the end of World War II, otter trawls have been introduced into the fisheries of South Africa, Egypt, India, and East Africa. This form of gear is operated from powered trawlers and has proved most successful.

Commercial, as well as subsistence fisheries throughout the South Pacific Islands, where the inhabitants are dependent upon fish as a source of food as well as a livelihood, have seen a similar expansion. This, too, can be largely attributed to the adoption of more efficient gear.

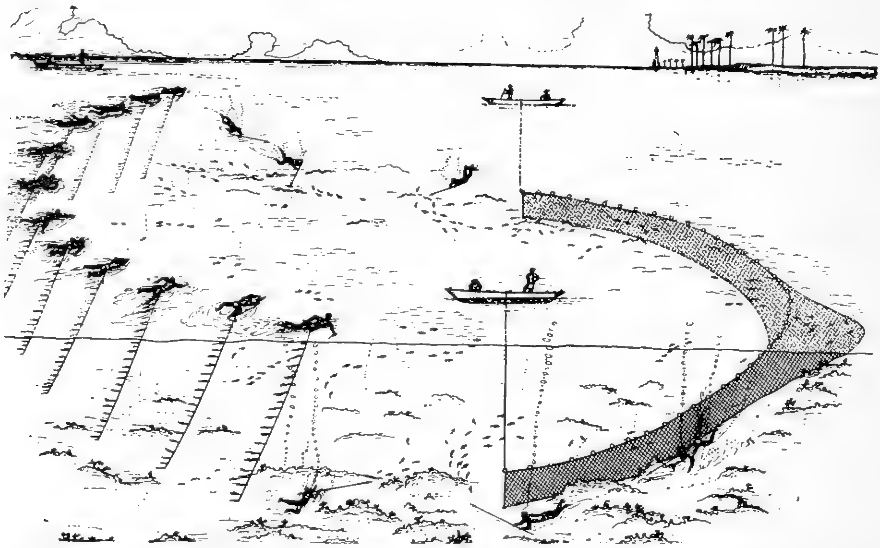


Fig. 13–37. Japanese "Driving-in net." As many as 100 fishermen and 10 boats are required to operate these nets designed for fishing in coral reef areas.

In general the fisheries of the tropical and south temperate zones, where previously the crudest forms of nets and boats were used, are today more comparable to the present high degree of fishery methods existing in the northern temperate zones of North America and Europe.

REFERENCES

Anon., "Fishery Resources of the United States," U. S. Senate Document No. 51, 79th Congress, 1st Session (1945).

Anon., "Typical Sardine, Tuna and Menhaden Seines," New York, The American Net and Twine Division of the Linen Thread Co., Inc., 1946.

Anon., "Japanese Fishing Gear," U. S. Fish and Wildlife Service, *Fishery Leaflet*, 234 (1947).

Anon., "Fishery Resources of Micronesia," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **239** (1947).

Anon., "The Fisheries and Fishery Resources of the Caribbean Area," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **259** (1947).

Anon., "Commercial Fishermen's Reference Book," Chicago, R. J. Ederer Co., 1948.

Anon., "Fishing Industry in Brazil," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **329** (1948).

Anon., "The Cuban Fishing Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **308** (1948).

Anon., "New Type Trawl (Shatz)," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **11**, No. 8, 33–34 (1949).

Anon., "German Commercial Electrical Fishing Device," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **349** (1949).

Anon., "Fishing Industry of the Gulf of Aden (Arabia)," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **328** (1949).

Anon., "Use of Wire in Long-Line Fishing," *Pacific Fishermen's News*, **6**, No. 2, 7 (1950).

Clark, G. H., "The California Halibut and an Analysis of the Boat Catches," Div. Fish and Game of California, *Fish. Bull.,* **32** (1931).

Firth, F. E., "Phenomenal Development of the Southern Trawl Fishery," *Fishing Gazette,* **49,** No. 12 (1932).

Firth, F. E., "Development of the Tuna Fishery in New England," *Year Book of the New England Fishing Industry,* 1940.

Firth, F. E., "Gloucester Mackerel Fleet Modernizes," Gloucester, *Master Mariner's Year Book,* 1942.

Firth, F. E., "Progress Report on Tests in Commercial Fisheries of Cordage Made from Various Fibers," U. S. Fish and Wildlife Service, *Spec. Rept.* (1944).

Firth, F. E., "Comparable Values of Fibers for Use in Commercial Fisheries," U. S. Fish and Wildlife Service, *Fishery Market News,* **6,** No. 8, 9–10 (1944).

Firth, F. E., "Eel Fishing and Eel Pots," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **127** (1945).

Firth, F. E., and Carlson, C. B., "Preservation and Care of Fish Nets," U. S. Fish and Wildlife Service, *Fishery Market News,* **5,** No. 7 (1942). Reissued as U. S. Fish and Wildlife Service, *Fishery Leaflet,* **66** (1947).

Firth, F. E., "Your Net Can Last Longer," *Pan-American Fishermen,* **3,** No. 2, 16, 49, 59 (1949).

Fry, D. H., Jr., "The Ring Net, Half Ring Net, or Purse Lampara in the Fisheries of California," California Div. of Fish and Game, *Fish. Bull.,* **27** (1930).

Knake, B. O., "Methods of Net Mending—New England," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **241** (1947).

Prytherch, H. F., "Improvement of Fishing Gear for Conservation of Immature Food Fishes," *Commercial Fisherman,* **2,** No. 4, 24–27 (1949).

Scofield, W. L., "Drift and Set Line Fishing Gear in California," Calif. Div. of Fish and Game, *Fish. Bull.,* **66** (1947).

Warfel, H. E., and Umali, A. F., "Reef Fishing in the Philippines," U. S. Fish and Wildlife Service, "Philippine Fishery Program" (1949).

CHAPTER 14

Fish and Shellfish as Food

Characteristics of Fresh Fish: Appearance, Chemical Composition, and Nutritive Value.

Physical Characteristics

When a fish dies it stiffens almost immediately, the flesh becoming rather firm and elastic. This condition is called *rigor mortis* and is a guarantee of perfect freshness. But since, even under the most favorable storage conditions, *rigor mortis* gradually disappears in a short time, its absence does not indicate that the fish is not sufficiently fresh to be an excellent food.

The flesh around the large caudal vein and kidney in fresh fish is light colored. As staleness approaches this flesh becomes discolored by the blood. This indicates that the fish has been caught for some time, but does not necessarily mean that it is unfit for food. The presence of this reddish discoloration on the ventral aspect of the backbone should cause the fish to be regarded with suspicion and other tests should be made to discover whether it is stale or putrid.

Since the personal factor enters largely into the judging of the condition of a fish by its odor and since fresh fish of different species vary considerably in this respect, the use of the sense of smell is invaluable in the examination of fish. Many individuals have difficulty in distinguishing between the odor of fresh fish and that of slightly tainted or stale fish, but few, if any, have trouble in discerning a putrid odor. Fresh fish, just taken from the water, usually have only a mild characteristic fishy odor, somewhat similar to that of seaweed. Fish which have not been eviscerated frequently give off odors suggestive of decomposition long before any spoilage of the flesh has taken place. This is usually caused by a rapid decomposition of the substance upon which the fish have been feeding.

The gills and the slime give off more pronounced decomposition odors than the flesh, and this may be useful in predicting incipient decomposition. The degree of odor is markedly affected by the temperature. Thus fish which are at 32° F (0° C) or below may have only a slight odor which might be increased to a relatively stale one if the fish were allowed to warm to 60° F (15.5° C) or above. The odor of fish kept in finely crushed ice ordinarily progresses from fishy, through sweet, stale, and finally putrid.

It requires considerable care to strip the flesh from the backbone of a strictly fresh fish, and many pieces are left adhering to the bone. When the fish becomes stale, the flesh comes away readily and comparatively cleanly from the bone. This is another test which may be applied to show relative freshness.

The condition of the kidney is a very important criterion in judging freshness. It is a very diffuse, vascular, and friable organ, and rapidly decomposes, passing through different shades of color, to form a reddish brown jelly like mass in a

few hours at ordinary temperatures. The abdominal walls also break down quickly. In fresh fish they are firm and elastic, but as the fish grow stale they lose their strength and become soft and pulpy.

A common criterion applied by nearly every housewife in the purchase of fish is the examination of the gills. The gills of most fish are red in color, with certain specific tints. These tints disappear in about 24 to 36 hours, and the gills become yellowish and then brown or gray and slimy by the third to fourth day if the fish are not kept at a low temperature. This test is not infallible as frequent washing aids in the retention of the color; moreover the gills of trawled fish are often paler at the time of capture than those of line fish; and, also, there are degrees of paleness even among perfectly fresh fish.

The eyes of fresh fish have a bright, transparent appearance which gradually becomes cloudy and often turns pink or gray with decomposition. The eyes of fresh fish often protrude, but when the fish are stale, the eyes tend to sink.

The slime on fresh fish is transparent, almost colorless, and usually not enough is present to be conspicuous except by feeling. As spoilage progresses, the slime increases, becomes turbid and finally thick and often of a yellow color. Presence of such slime is good evidence that the fish is not fresh, but its absence is meaningless since it can easily be removed.

The characteristics of fresh fish and bad fish are presented in Table 63:

TABLE 63. CHARACTERISTICS OF FRESH AND STALE FISH.

Good Fish	Bad Fish
Skin and colors bright	Skin dull, spotted, or slimy; colors pale or bleached
Scales adhere strongly	Scales loose
Eyes clear and not sunken or wrinkled	Eyes cloudy, wrinkled, sunken
Gills red	Gills yellowish, gray, brown
Flesh firm and elastic; finger impressions do not remain	Flesh flabby and soft; finger impressions remain
Smell fresh, at exterior and gills	Smell stale or sour, especially at gills
Little slime on skin (usually slime present but clear on halibut)	Skin slimy (usually). In some species the slime is coagulated or lumpy; in halibut the slime leaves the fish
Body rigid or stiff	Body flabby or limp
Fish sinks in water (usually), although some will float if gassy	Fish floats in water (if very bad)

Chemical Characteristics of Fresh Fish

As previously indicated one of the first changes occurring after the death of a fish is the onset of *rigor mortis*. Chemically an increase in the amount of lactic acid and a very slight increase in hydrogen-ion concentration are noted. While the fish is still in *rigor mortis*, or immediately after it passes off, the proteolytic enzymes begin to hydrolyze the highly complex protein of the fish muscle into simpler proteins, polypeptides, and amino acids.

A second process, usually accompanying autolysis, is bacterial decomposition. The result of bacterial actions on proteins is the formation of the same type of

compounds as are produced during autolysis, such as polypeptides and amino acids. These are only intermediate products and are later decomposed into a wide variety of substances, including ammonia, amines, indole, hydrogen sulfide, and skatol, many of which have disagreeable odors. Most of the end products of bacterial decomposition of fish are basic, so that a rise in the pH is observed. However, when bacterial decomposition occurs at low temperatures, as when the fish is packed in ice, the principal products are the intermediate ones.

Stansby and Lemon (1933) have indicated that, although fish decomposition is usually classified as bacterial or autolytic, a more satisfactory test for freshness is based upon the type of products formed: (1) primary changes, which lead to the formation of amino acids from protein or to any intermediate product such as polypeptides and peptones; (2) secondary changes, including those which lead to the formation of such products as amines, indole, hydrogen sulfide, and skatol which detract from the value of the fish and usually contribute disagreeable flavors or odors. Although the primary changes which occur in the proteins of fish flesh do not cause the formation of compounds having foul odor and flavor, other objectionable changes do occur.

As the protein molecule hydrolyzes, the fish becomes softer. In extreme cases juices, which contain dissolved protein, amino acids, and minerals, run from the fish. Furthermore, a fish in which primary changes have occurred is much more readily decomposed into secondary decomposition products when exposed to high temperatures and the action of bacteria. The secondary decomposition is generally considered to be the result of bacterial action and the end products are chiefly basic. This type of decomposition is usually considered as fish spoilage and renders the fish inedible.

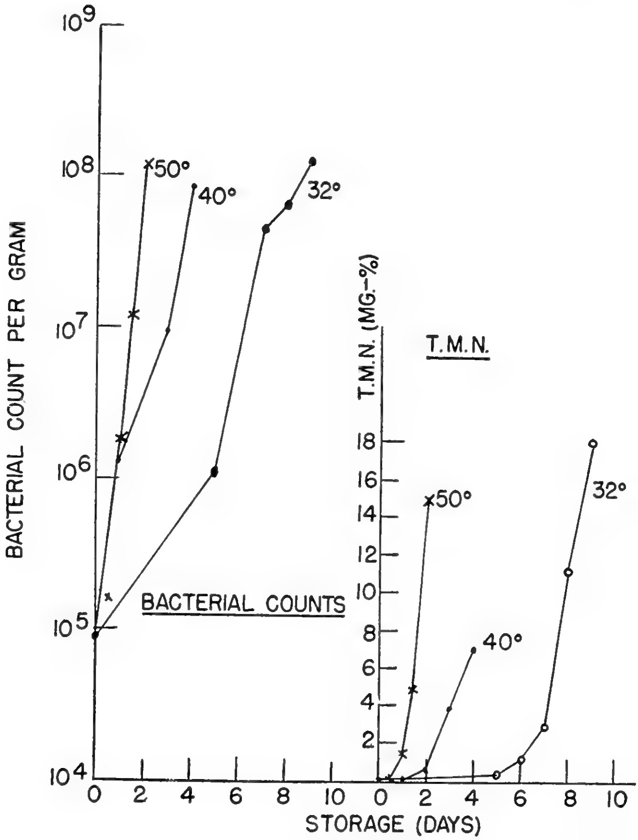
When freshly caught fish are packed in ice, primary changes are the chief types of degradation occurring for the first few weeks. If the fish have been packed in ice for longer than a few days and are then removed from the ice, secondary decomposition sets in very rapidly and true spoilage occurs.

Nickerson, Goldblith, and Proctor (1950) have recently obtained some very valuable data concerning the bacterial and enzymatic changes which occur during the holding of mackerel under various conditions of temperature and sterility, as well as similar facts concerning the changes occurring during the refrigerated storage of haddock and haddock fillets (Proctor, Nickerson and Goldblith, 1950). They found that trimethylamine and volatile acids increase in haddock fillets stored under refrigeration only when bacteria are present in significant numbers. Increases in trimethylamine and volatile acids seem to be correlated with the levels of the microorganisms present. Autolysis was not found to be an important factor in spoilage. Trimethylamine and volatile acids produced by the action of bacteria on the surface tissues of eviscerated haddock held in crushed ice effuse into the flesh and accumulate in the deeper tissues. They also noted that iced whole, non-eviscerated fish do not spoil as quickly as eviscerated fish similarly refrigerated.

A number of tests for the degree of freshness of fish have been proposed. Almy (1925) has suggested one based on the presence of hydrogen sulfide as an indication of decomposition. The Tillmans and Otto (1927) test involves the determination of ammonia. Other tests have been described by Fellers, Shostrom, and Clark (1924), Clough (1922), Tressler (1919), Tillmans, Hirsch, and

Kuhn, (1927), Benson and Wells (1911), Stansby and Lemon (1933), and Lang, Farber, and Yerman (1945).

The test devised by Stansby and Lemon (1933) for the determination of the relative freshness of haddock involves the electrometric titration of a sample suspension of the ground flesh. This notes the volume of standard hydrochloric



(Courtesy B. E. Proctor, J. T. R. Nickerson and S. A. Goldblith)

FIG. 14–1. Effects of different storage temperatures on bacterial count and trimethylamine nitrogen content of haddock fillets (non-irradiated).

acid solution required to bring the pH to 5.97 (B value) and then to 4.28 (A value). In general the higher the A values and the lower the B values the fresher the haddock.

The Lang, Farber, and Yerman method (1945) involves the passage of a current of purified air through a quantity of juice pressed from the fish under test and then through an oxidizing reagent (a standard solution of alkaline potassium permanganate) of known strength and volume. The amount of reduction of the permanganate is considered to be an index of the amount of spoilage of the fish.

TABLE 64. PERCENTAGE COMPOSITION OF EDIBLE PART OF FISH (FRESH BASIS).

Common Name of Fish	When Caught	Solids	Fat	Ash	NITROGEN Total	Cold Water Soluble	Coagulable	Hot Water Soluble	Ammonia
Bluefish	May 7	23.83	1.54	1.16	3.36	0.760	0.320	0.071	0.0185
Bluefish	Sept. 28	29.04	8.10	1.11	3.26	0.730	0.360	0.085	0.0180
Butterfish	May 19	25.66	5.96	1.49	2.89	0.862	0.498	0.020	0.0162
Butterfish	Oct. 12	30.01	13.52	1.40	2.92	0.850	0.430	0.021	0.0180
Croaker	Apr. 10	20.77	1.25	1.18	2.85	0.813	0.447	0.141	0.0140
Croaker	Sept. 8	24.26	3.23	1.37	—	0.880	0.410	0.130	0.0230
Flounder	Apr. 19	17.54	0.20	1.17	2.56	0.880	0.477	0.117	0.0143
Flounder	Sept. 22	21.59	0.37	1.34	2.54	0.740	0.330	0.200	0.0190
Haddock	Apr. 2	18.32	0.15	1.11	2.33	0.748	0.343	0.147	0.0220
Haddock	Aug. 31	20.83	0.09	1.01	2.59	0.800	0.520	0.150	0.0220
Striped bass	Apr. 16	25.70	3.58	1.26	3.21	1.153	0.719	0.102	0.0170
Striped bass	Oct. 16	19.83	2.98	1.26	3.07	1.050	0.650	—	0.0166
Sea bass	May 12	22.02	1.61	1.23	2.98	0.967	0.532	0.106	0.0159
Sea bass	Sept. 14	19.44	1.60	1.09	—	0.970	0.700	—	0.0220
Spanish mackerel	June 4	33.01	12.59	1.20	3.13	0.846	0.458	0.055	0.0185
Spanish mackerel	Oct. 26	35.70	16.24	1.11	3.09	0.890	0.570	0.102	0.0240
Weakfish	May 1	21.41	2.34	1.25	2.83	1.118	0.851	0.203	0.0134
Weakfish	Sept. 25	19.35	0.52	1.20	—	0.820	0.500	0.290	0.0150
Shad (male)	Apr. 2	35.32	14.43	1.34	3.18	1.112	0.621	0.074	0.0160
Shad (female)	Apr. 13	34.17	13.93	1.40	3.00	1.147	0.685	0.063	0.0182
Shad (female)	May 22	26.00	5.87	1.29	2.91	0.980	0.549	0.058	0.0190
Shad (female) spent	June 19	23.38	2.95	1.53	2.98	0.975	0.549	0.182	0.0178

Source: Clark, E. D., and Almy, L. H., "A Chemical Study of Food Fishes," *J. Biol. Chem.*, 33, 483–498 (1918).

Lang, Farber, and Yerman have shown that this method is of considerable value for estimating the spoilage of tuna.

Proximate Composition

The percentage of fat in different species of fish varies widely. Salmon, shad, herring, butterfish, and mackerel are well-known fatty fish, whereas cod, haddock, cusk, pollock, and flounder have long been recognized as lean fish.

Many other factors also influence the amount of fat in the individual fish. The larger, older fish, especially those of the same school, are often fatter than the smaller fish as they are stronger and thus are able to seize more food. Female fish during the early development of the ovaries are usually fatter than male fish of the same schools. Fish caught on excellent feeding grounds are fatter than those caught elsewhere.

Clark and Almy, who made a study of the common food fishes of the Philadelphia markets, with especial reference to a seasonal variation in composition, concluded that, of the 10 marine fishes examined at different seasons of the year, 9 species showed a definite tendency toward a seasonal variation in composition (Tables 64 and 65). The fatty fishes, bluefish, butterfish, and Spanish mackerel, were relatively lean in the spring, but were high in fat in the autumn.

TABLE 65. PERCENTAGE COMPOSITION OF EDIBLE PART OF FISH (Calculated on Dry Basis).

Common Name of Fish	When Caught	Fat	Ash	NITROGEN				
				Total	Cold Water Soluble	Coagulable	Hot Water Soluble	Ammonia
Bluefish	May 7	6.45	4.87	14.10	3.19	1.35	0.30	0.078
Bluefish	Sept. 28	27.86	3.81	11.21	2.51	1.24	0.29	0.061
Butterfish	May 19	23.27	5.81	11.28	3.36	1.94	0.08	0.063
Butterfish	Oct. 12	45.02	4.66	9.72	2.83	1.43	0.70	0.059
Croaker	Apr. 10	6.02	5.68	13.72	3.91	2.15	0.68	0.067
Croaker	Sept. 8	13.30	5.64	—	3.62	1.69	0.54	0.094
Flounder	Apr. 19	1.14	6.67	14.60	5.06	2.72	0.67	0.082
Flounder	Sept. 22	1.71	6.20	11.76	3.42	1.90	0.90	0.087
Haddock	Apr. 2	0.81	6.06	12.72	4.08	1.87	0.80	0.120
Haddock	Aug. 31	0.42	4.84	12.43	3.84	2.50	0.72	0.105
Striped bass	Apr. 16	13.94	4.90	12.50	4.48	2.80	0.40	0.066
Striped bass	Oct. 16	15.01	6.35	15.47	5.39	3.29	—	0.084
Sea bass	May 12	7.32	5.59	13.55	4.39	2.42	0.48	0.072
Sea bass	Sept. 14	8.22	5.60	—	5.08	3.55	—	0.113
Spanish mackerel	June 4	38.14	3.63	9.48	2.56	1.39	0.17	0.056
Spanish mackerel	Oct. 26	45.47	3.10	7.38	2.49	1.60	0.29	0.067
Weakfish	May 1	10.94	5.85	13.23	5.53	3.98	0.95	0.063
Weakfish	Sept. 25	2.68	6.19	—	4.63	2.58	1.49	0.077
Shad (male)	Apr. 2	40.85	3.80	9.01	3.15	1.768	0.21	0.045
Shad (female)	Apr. 13	40.75	4.10	8.78	3.35	2.005	0.18	0.053
Shad (female)	May 22	22.58	4.97	11.20	3.77	2.113	0.23	0.074
Shad (female) spent	June 19	12.62	6.54	12.75	4.17	2.348	0.78	0.076

Source: Clark, E. D., and Almy, L. H., "A Chemical Study of Food Fishes," *J. Biol. Chem.*, 33, 483–498 (1918).

Female fish were found to be high in fat for a month or so before spawning and very low in fat immediately after spawning.

A consideration of their results and a comparison of the many published analyses of fish make it plain that a single analysis, even if based on large numbers of individuals, cannot be accepted as representing a typical composition. The great bulk of the proximate analyses of fish are therefore of little value, except that they may be used for the classification of fish into two general groups: fatty and nonfatty (fish of low fat content).

Clark and Almy have shown that the protein content is approximately the same in both fatty and nonfatty fish. They conclude that "as the fat content increases, the water content decreases, the protein remaining practically the same." This relation is shown by their figures for blackfish, bluefish, Spanish mackerel, and shad in Table 66.

TABLE 66. RELATION BETWEEN THE AMOUNTS OF FAT, WATER, AND NITROGEN IN THE FLESH OF FISH.

Kind of Fish	Water	Solids	Fat	Fat-free Solids
	(Per Cent)	(Per Cent)	(Per Cent)	(Per Cent)
Blackfish	79.10	20.90	0.15	20.75
Bluefish	70.96	29.04	8.10	20.94
Spanish mackerel	66.99	33.01	12.59	20.42
Shad	64.68	35.32	14.43	20.89

Source: Clark, E. D., and Almy, L. H., "A Chemical Study of Frozen Fish in Storage for Long and Short Periods," *Ind. Eng. Chem.*, **12,** 656–663 (1920).

Table 67 by Manning (1935) presents the protein, fat, and vitamin content of a number of fish and shellfish.

Nature of Constituents

Unfortunately relatively little work has been done to determine the exact chemical nature of the organic substances forming the tissues of fish. It is mainly the muscular tissue which serves as a foodstuff and therefore its composition will be given the chief consideration in this chapter. The muscular tissue of fish consists chiefly of water, proteins, and more or less fat. As the chemical nature of fish fats is considered in some detail in the section on fish oils (Chapter 22), a duplication of the discussion is unnecessary.

Nitrogenous Compounds

The nitrogenous compounds occurring in fish muscle are for the most part similar in nature to those found in the muscles of the higher vertebrates, except that they contain more collagen and less extractives.

Extractives. Various writers have shown that histidine, hypoxanthine, carnosine, tyrosine, creatine, and creatinine are the principal organic compounds obtained by aqueous extraction of fresh fish muscle. The presence of imidazo-ethylamine, leucine, and alanine has also been reported. Okuda found the amounts of creatine and creatinine in the aqueous extract of the fresh muscle of marine fish shown in Table 68 (p. 289).

TABLE 67. PROTEIN, FAT, AND VITAMIN CONTENT OF SOME FISH AND SHELLFISH (Edible Portions).

Commodity	Vitamins	Protein (Per Cent)	Fat (Per Cent)
Alewives	A,B	19	5
Blue pike	A,B	19	0.5
Butterfish	A,B	18	11
Catfish and bullheads	A,B	14	21
Clams	A,B,D,G	9	1
Crabs	A,B,G	17	2
Croaker	A,B	18	3
Flounder	A,B	14	0.6
Haddock	A,B,G	17	0.3
Hake	A,B	15	0.7
Halibut	A,B	19	5
Herring (lake)	A,B	19	3
Herring (sea)	A,B,D	19	11
Lake trout	A,B	18	10
Lobsters	A,B	16	2
Mackerel	A,B	19	7
Mullet	A,B	19	5
Oysters	A,B,D,G	6	1
Pollock	A,B	22	0.8
Salmon	A,B,D,G	22	13
Sardine (pilchard)	A,B,D	25	13
Scup	A,B	19	5
Shad	A,B	19	9
Sheepshead (fresh water)	A,B	20	4
Shrimp	A,B,D	25	1
Squeteague or sea trout	A,B	19	2
Whitefish	A,B	23	7
Whiting	A,B	15	0.4

Source: Manning, J. R., "Fish and Shellfish for Food," U. S. Bureau of Fisheries, *Special Memo*, 2256B (1935).

TABLE 68. CREATINE AND CREATININE CONTENT OF SOME FISH.

Name	In 100 Parts of Fresh Substance			In 100 Parts of Dry Matter	
	Water	Creatine	Creatinine	Creatine	Creatinine
Bonito (*Gymnosarda affinis*)	72.165	0.649	0.134	2.011	0.481
Tunny (*Thunnus schlegeli*)	72.402	0.497	0.064	1.800	0.232
Japanese porgy (*Pagrus major*)	77.340	0.754	0.070	3.327	0.308
Shark	79.800	0.655	0.134	3.242	0.663

Source: Okuda, Y., "Quantitative Determination of Creatin, Creatinine and Monoaminoacids in Certain Fishes, Mollusca and Crustacea," *J. Coll. Agr. Tokyo Imp. Univ.*, 5, 25–31 (1912–1916).

Distribution of Nitrogen. Several workers have studied the form of the nitrogen of fish flesh and have shown that it is chiefly albuminous nitrogen. The results of Okuda's analyses of the bonito, the Japanese porgy, and the tunny are given in Table 69. Drummond's data concerning the form of nitrogen of herring and cod muscle and the results of Osborne and Heyl's study of halibut muscle are given in Table 70 and are compared with similar analyses of ox and chicken muscle.

TABLE 69. FORM OF NITROGEN IN CERTAIN MARINE FISH.

	Bonito (*Gymnosarda affinis*)		Japanese Porgy (*Pagrus major*)		Tunny (*Thunnus schlegeli*)	
	In 100 g of fresh flesh	In 100 g of dry flesh	In 100 g of fresh flesh	In 100 g of dry flesh	In 100 g of fresh flesh	In 100 g of dry flesh
Water	69.371	—	76.787	—	73.516	—
Dry matter	30.629	100.000	23.213	100.000	26.484	100.000
Total N	4.479	14.621	3.121	13.445	3.549	13.397
Alb. N	3.799	12.401	2.685	11.584	—	—
Non-alb. N	0.680	2.220	0.432	1.861	—	—
Warm water soluble N	1.628	5.314	1.025	4.419	1.530	5.776
Of which protein N	0.948	3.094	0.593	2.555	0.812	3.065
Organic base N	0.189	0.617	0.088	1.379	0.285	1.076
Monoamino N	0.022	0.072	0.016	0.069	0.011	0.041
Ammonium N	Trace	Trace	Trace	Trace	Trace	Trace

Source: Okuda, Y. "Quantitative Determination of Creatin, Creatinine and Certain Monoaminoacids in Certain Fishes, Mollusks and Crustacea," *J. Coll. Agr. Tokyo Imp. Univ.*, **5**, 25–31 (1912–1916).

From these data it is seen that the analysis of halibut muscle is approximately the same as that of chicken muscle, except that the humin nitrogen of the former is somewhat higher. Other observers have reported the humin nitrogen content of chicken muscle as high as 2.74 per cent.

TABLE 70. FORM OF NITROGEN IN HALIBUT, COD, AND HERRING MUSCLE.

Protein	Amide N (Per Cent)	Humin N (Per Cent)	Monoamino N (Per Cent)	Diamino N (Per Cent)
Halibut	6.70	2.37	60.80	30.20
Cod	5.82	2.30	61.20	30.00
Herring	6.05	2.64	61.40	29.70
Ox	5.51	2.66	64.40	27.30
Chicken	6.63	1.76	61.55	30.27

Source: Osborne, T. B., and Heyl, F. W., "Hydrolysis of Fish Muscle," *Am. J. Physiol.*, 23, 81–89 (1908).

Composition of the Proteins. Osborne and Heyl studied the products of hydrolysis of halibut (*Hippoglossus hippoglossus*) muscle and more recently Okuda

and Oyama have studied the composition of the proteins of the muscle of the Japanese porgy (*Pagrus major*). Okuda (1919) has determined the cleavage products of both the ordinary flesh and the dark flesh ("chiai"), which occurs in the lateral muscles of the bonito. Okuda, Okimoto, and Yada (1919) have pub-

TABLE 71. PRODUCTS OF THE HYDROLYSIS OF MUSCLE PROTEINS IN PER CENT OF ASH- AND MOISTURE-FREE SUBSTANCES.

	Porgy [a] (*Pagrus major*)	Halibut [b] (*Hippoglossus hippoglossus*)	Chicken [b]	Bonito [c] (*Katuswonus pelamis*) Ordinary flesh	Bonito [c] (*Katuswonus pelamis*) Chiai flesh	Cod [d] (*Gadus morhua*)
Glycine	Absent or trace	Absent	0.68	0.0	0.0	0.0 or trace
Alanine	1.04	?	2.28	2.3	1.1	3.53
Valine	0.60	0.79	?	2.8	1.8	3.88
Valine containing leucine	2.17	—	—	—	—	—
Leucine	8.82	10.33	11.19	10.4	9.2	2.46
Proline	1.22	3.17	4.74	3.1	3.0	1.68
Phenylalanine	4.72	3.04	3.53	4.1	1.6	2.31
Aspartic acid	1.66	2.73	3.21	3.3	3.2	0.61
Glutamic acid	1.63	10.13	16.48	8.1	12.1	5.24
Serine	?	?	?	?	?	0.51
Tyrosine	2.64	2.39	2.16	2.1	2.9	2.46
Arginine	5.15	6.34	6.50	7.8	7.08	6.68
Histidine	2.07	2.55	2.47	3.04	3.16	2.29
Lysine	6.28	7.45	7.94	7.41	6.78	8.35
Ammonia determined	1.32	1.33	1.67	0.64	0.78	0.75
Ammonia isolated	1.04	—	—	—	—	—
Tryptophane	+	+	+	+	+	+
Guanine	—	—	—	0.09	0.12	—
Adenine	—	—	—	0.04	0.1	—
Xanthine	—	—	—	?	?	—
Hypoxanthine	—	—	—	0.08	0.03	—

Source:

[a] Okuda, Y., and Oyama, K., "Hydrolysis of Fish Muscle," *J. Coll. Agr. Tokyo Imp. Univ.*, **5**, 365–372 (1916).

[b] Osborne, T. B., and Heyl, F. W., "Hydrolysis of Fish Muscle," *Am. J. Physiol.*, **23**, 81–89 (1908).

[c] Okuda, Y., Okimoto, T., and Yada T., "Hydrolysis of the Muscle Proteins of the Whale and the Cod," *J. Coll. Agr. Tokyo Imp. Univ.*, **7**, 29–37 (1919).

[d] Okuda, Y., "Chemistry of 'Chiai' Flesh," *J. Coll. Agr. Tokyo Imp. Univ.*, **7**, 1–28 (1919).

lished similar work on the flesh of the cod. Their results are presented in Table 71, together with Osborne and Heyl's (1908) analyses of chicken muscle which may be used for comparison.

More recently Pottinger and Baldwin (1946) have determined the amount of arginine, histidine, lysine, tryptophane, and cystine in the proteins from the edible portions of a number of fish, shellfish, and Crustacea. Their data, presented in Table 72, show that the proteins of fish, shellfish, and Crustacea are good

TABLE 72. PERCENTAGE OF ARGININE, HISTIDINE, LYSINE, TRYPTOPHANE, AND CYSTINE IN THE PROTEINS FROM THE EDIBLE PORTIONS OF FISH, SHELLFISH, AND CRUSTACEA.

Species	Scientific name	Date sample was prepared	Arginine	Histidine	Lysine	Tryptophane	Cystine [a]
Catfish	*Ameiurus catus*	Aug. 1937	—	—	—	0.97	—
Cod	*Gadus morhua*	June 1936	5.58	1.72	6.83	1.06	1.41
Croaker	*Micropogon undulatus*	May 1936	5.81	1.37	6.10	1.24	1.15
Haddock	*Melanogrammus aeglefinus*	Sept. 1935	5.70	1.17	6.41	0.85	1.16
Halibut	*Hippoglossus hippoglossus*	Dec. 1936	6.00	1.66	6.16	1.64	1.45
Herring:							
Lake	*Leucichthys artedi*	Nov. 1937	—	—	—	1.25	—
Sea	*Clupea harengus*	March 1937	5.09	1.56	7.03	1.23	—
Lake trout	*Cristivomer namaycush*	June 1937	5.73	1.40	7.15	1.17	—
Mackerel:							
Boston	*Scomber scombrus*	Aug. 1936	5.78	1.93	7.13	1.36	1.18
Spanish	*Scomberomorus maculatus*	Jan. 1936	5.27	1.48	6.53	1.37	1.25
Mullet	*Mugil species*	Feb. 1937	5.78	1.61	6.74	1.36	1.29
Pilchard	*Sardina caerulea*	March 1937	5.60	1.23	6.78	1.30	—
Red snapper	*Lutianus blackfordii*	Nov. 1936	6.18	1.57	6.72	1.22	1.29
Salmon:							
Chum	*Oncorhynchus keta*	May 1938	5.55	1.30	5.69.	1.33	—
King	*Oncorhynchus tschawytscha*	April 1937	5.02	1.41	6.27	1.20	1.27
Pink	*Oncorhynchus gorbuscha*	April 1937	—	—	—	1.09	1.15
Silver	*Oncorhynchus kisutch*	Jan. 1937	5.68	1.87	6.57	1.44	1.39
Sockeye	*Oncorhynchus nerka*	Sept. 1937	—	—	—	1.25	—
Shad	*Alosa sapidissima*	May 1936	4.54	1.09	6.45	1.22	1.17
Squeteague or sea trout	*Cynoscion regalus*	June 1937	5.90	1.42	6.78	1.01	—
SHELLFISH and CRUSTACEA							
Clam, hard	*Venus mercenaria*	Sept. 1936	5.27	1.45	5.40	1.19	—
Crab, blue	*Callinectes sapidus*	Nov. 1936	7.61	1.51	6.38	1.11	—
Oyster	*Ostrea virginica*	Oct. 1936	5.71	1.79	5.24	1.67	—
Shrimp	*Peneus brasiliensis*	June 1936	7.50	1.61	7.35	0.96	1.25

[a] Cystine determinations were conducted by H. C. Harris, Fishery Technological Laboratory, College Park, Maryland.
Source: Pottinger, S. R., and Baldwin, W. H., U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **8**, No. 8, 5–9 (1946).

sources of these essential amino acids. With the exception of the values for the arginine content of shellfish and Crustacea the percentages of the 5 amino acids determined are comparatively uniform for the different species.

Inorganic Constituents. Clark and Almy's figures (Table 65) indicate that the water-free substance of the flesh of the common marine fishes contains from about 3 to 7 per cent of ash. Data concerning the composition of the ash of a few important fishes as determined by Atwater (1892) and Riddell (1936) are presented in Table 73.

TABLE 73. PERCENTAGE COMPOSITION OF ASH OF COMPOSITE SAMPLES OF VARIOUS CANNED BRITISH COLUMBIA FOOD FISHES.

Species of fish	CaO (Per Cent)	MgO (Per Cent)	P_2O_5 (Per Cent)	SO_3 (Per Cent)	K_2O (Per Cent)	Na_2O (Per Cent)	Cl (Per Cent)	Cu (mg per g ash)	Mn (mg per g ash)
Fraser pink salmon	10.71	2.05	23.91	1.18	19.78	20.05	18.42	.051	.009
Early Fraser sockeye salmon	13.03	2.16	27.30	0.26	20.59	16.92	15.50	.070	.015
Late Fraser sockeye salmon	14.79	2.30	30.00	0.70	21.62	12.54	9.80	.120	.000
Blueback salmon	15.85	2.07	27.32	0.13	16.91	13.45	13.45	.034	.102
Pilchard	13.07	2.11	20.00	0.34	13.59	22.70	25.74	.032	.034
Haddock	3.39	1.90	13.70	0.31	13.84	36.51	38.10		
Pike	7.38	3.81	38.16	2.50	23.92	20.45	4.74		

Source: Atwater, W. O., "The Chemical Composition and Nutritive Values of Food Fishes and Aquatic Invertebrates," *U. S. Fish Comm. Rept.*, **1888**, 679–868 (1892). Riddell, W. A., "Nutritive Value of Marine Products. XII Mineral Constituents of Some Food fishes of British Columbia," *J. Biol. Bd. Can.*, 2, 469–472 (1936).

Nilson and Coulson (1939) determined the mineral content of the fillets (bone and skin-free muscle) of a number of different species of fish. Their data are summarized in Table 74 (p. 294). In general the mineral content of the fillets is similar to that of beef round, except that beef contains more iron and much less iodine.

Newell and McCollum (1931) spectroscopically examined the ash of 7 species of fish and found that all contained considerable amounts of calcium, iron, magnesium, phosphorus, potassium, and sodium. Aluminum, chromium, copper, lead, lithium, manganese, and strontium were present as traces in all the species, while fluorine, nickel, silver, tin, titanium, and zinc were present as traces in some species and columbium and vanadium were doubtful.

Tressler and Wells (1924) determined the iodine content of a considerable number of marine and fresh-water fish, mollusks, and crustaceans. Clams, oysters, and lobsters were found to be relatively high in iodine. Scallops, crabs, and most marine fish were also found to contain far more iodine than fresh-water fish. The results of their analyses are given in Table 75 (pp. 294–296).

Composition of Shellfish and Crustacea

The proximate composition of a number of different shellfish has been presented in Table 67 (p. 289). Some data concerning the amino acid content of clams, crabs, oysters, and shrimp are given in Table 72 (p. 292).

TABLE 74. THE MINERAL CONTENT OF FILLETS.
(Per Cent by Weight of the Fresh Edible Portion).

Species	No. samples	Dry matter [a]	Calcium	Magnesium	Phosphorus	Iron	Copper	Iodine
Cod (*Gadus morhua*)	4	17.7	0.0110	0.0280	0.1859	0.000518	0.000041	0.000103
Haddock (*Melanogrammus aeglefinus*)	4	18.7	.0165	.0236	.1731	.000516	.000041	.000513
Mackerel (*Scomber scombrus*)	2	19.9	.0048	.0281	.2169	.001224	.000115	.000053
Red snapper (*Lutianus blackfordii*)	3	21.7	.0162	.0276	.2279	.001158	.000038	.000031
Mullet (*Mugil cephalus*)	3	23.9	.0261	.0318	.2198	.001779	.000082	.000485
Pilchard, California (*Sardina caerulea*) [b]	2	20.5	.0422	.0237	.2115	.002483	.000166	.000013
Flounder (*Pleuronectedae* species)	2	21.3	.0117	.0305	.2053	—	—	.000029
Lake herring (*Leucichthys artedi*)	1	17.9	.0116	.0172	.1518	—	—	—

[a] Samples first dried on steam bath and finished in electric air oven at 176° F (80° C).
[b] Whole fresh fish.

Note. Four units to the right of the decimal point equals parts per million (or mg per kg).

Source: Nilson, H. W., and Coulson, E. J., "The Mineral Content of the Edible Portions of Some American Fishery Products," U. S. Bureau of Fisheries, *Investigational Rept.*, 41 (1939).

TABLE 75. IODINE CONTENT OF SEA FOODS.

Kind of sea food	Fresh substance		Water-free substance	
	Mg I per kilogram	Parts per billion	Mg I per kilogram	Parts per billion
Mollusks:				
Clams, hard (*Venus mercenaria*)	1.37	1,370	6.20	6,200
Oysters (*Ostrea elongata* Solander [1])	1.16	1,160	6.00	6,000
Oyster juice from "selects"	.12	120	3.17	3,170
Scallops, giant (*Pecten grandis*)	.15	150	.81	810
Crustaceans:				
Crabs, blue (*Callinectes sapidus*):				
Soft, whole	.09	90	.49	490
Meat flakes	.18	180	.87	870
Lobster (*Homarus americanus*)	1.38	1,380	11.59	11,590
Shrimp (*Peneus setiferus*), headed	.45	450	2.25	2,250

TABLE 75. IODINE CONTENT OF SEA FOODS. (*Continued*)

Kind of sea food	Fresh substance		Water-free substance	
	Mg I per kilogram	Parts per billion	Mg I per kilogram	Parts per billion
Marine fish:				
Bluefish (*Pomatomus saltatrix*)	.26	260	1.87	1,870
Cod (*Gadus morhua*)	.24	240	1.00	1,000
Haddock (*Melanogrammus aeglefinus*)	.29	290	1.05	1,050
Halibut (*Hippoglossus hippoglossus*)	.25	250	.83	830
Mackerel—				
Common (*Scomber scombrus*)	.14	140	.33	330
Spanish (*Scomberomorus maculatus*)	.40	400	1.41	1,410
Pollock (*Pollachius virens*)	.12	120	.90	900
Pompano (*Trachinotus carolinas*)	.08	80	.25	250
Scup (*Stenotomus chrysops*)	.30	300	.95	950
Spot (*Leiostomus xanthurus*)	.59	590	1.40	1,140
Spotted squeteague (*Cynoscion nebulosus*)	.02	20	.08	80
Squeteague (*Cynoscion regalis*)	.23	230	.85	850
Tautog (*Tautoga onitis*)	.27	270	1.17	1,170
Winter flounder (*Pseudopleuronectes americanus*)	.18	180	.73	730
Anadromous fishes:				
Alewives (*Pomolobus pseudoharengus*), smoked	.26	260	.50	500
Rock (*Roccus lineatus*)	.45	450	2.00	2,000
Smelt (*Osmerus mordax*)	.01	10	.07	70
White perch (*Morone americana*)	.42	420	1.42	1,420
Fresh-water fishes from Lake Erie:				
Cisco, smoked	.24	240	.55	550
Cisco roe, smoked	.27	270	.87	870
Lake trout (*Salvelinus namaycush*)	.01	10	.04	40
Whitefish (*Coregonus clupeiformis*)	.03	30	.11	110
Fresh-water fishes from the Potomac River:				
Bass, largemouth black (*Micropterus salmoides* Lacépède)	.05	50	.19	190
Perch, yellow (*Perca flavescens*)	.02	20	.09	90
Pickerel, eastern (*Lucius reticulatus* LeSueur)	.07	70	.30	300
Fresh-water fishes from the Mississippi River at Fairport, Iowa:				
Bass, largemouth black (*Micropterus salmoides*)	.01	10	.04	40
Black bullhead (*Ameiurus melas*)	.01	10	.04	40
Bluegill (*Lepomis incisor*)	.04	40	.18	180
Bowfin (*Amiatus calva*)	.02	20	.08	80
Buffalo fish:				
Bigmouth (*Ictibus cyprinella*)	.02	20	.08	80
Razorback (*Ictiobus bubalus*)	.02	20	.08	80
Carp (*Cyprinus carpio*)	.01	10	.04	40
Carp sucker (*Carpiodes difformis*)	.03	30	.13	130
Channel catfish (*Ictalurus punctatus*)	.01	10	.04	40

TABLE 75. IODINE CONTENT OF SEA FOODS. (*Continued*)

Kind of sea food	Fresh substance		Water-free substance	
	Mg I per kilogram	Parts per billion	Mg I per kilogram	Parts per billion
Drum, fresh-water (*Aplodinotus grunniens*)	[2]	[3]	[4]	[5]
Gar pike (*Lepisosteus osseus*)	.01	10	.04	40
Gizzard shad (*Dorosoma cepedianum*)	.01	10	.04	40
Spotted sucker (*Minytrema melanopes*)	[2]	[3]	[4]	[5]
White crappie (*Pomoxis annularis*)	.01	10	.03	30
Marine mammal: Whale steak, canned	[2]	[3]	[4]	[5]

[1] Same as *Ostrea virginica*.
[2] Less than 0.01.
[3] Less than 10.
[4] Less than 0.04.
[5] Less than 40.

Source: Tressler, D. K., and Wells, A. W., "Iodine Content of Sea Foods," U. S. Bureau of Fisheries, *Doc.*, **967** (1924).

The data concerning the mineral content of crustacea and shellfish obtained by Nilson and Coulson (1939) are presented in Table 76.

TABLE 76. THE MINERAL CONTENT OF SHELLFISH AND CRUSTACEA. (Per Cent by Weight of the Fresh Edible Portion).

Species	No. samples	Dry matter [a]	Calcium	Magnesium	Phosphorus	Iron	Copper	Iodine
Oysters, Eastern (*Ostrea virginica*)	4	15.0	0.0579	0.0320	0.1121	0.006100	0.003730	0.000049
Oysters, Pacific natives (*Ostrea lurida*)	2	17.9	.0632	.0242	.1540	.004940	.001240	.000030
Oysters, Pacific, Japanese (*Ostrea gigas*)	2	21.4	.0628	.0480	.1922	.007510	.001230	.000036
Shrimp, raw (*Peneus brasiliensis*)	4	20.0	.0542	.0421	.2285	.002188	.000331	.000023
Shrimp, boiled	2	28.7	.0614	.0509	.2432	.003973	.000302	.000021
Blue crab, white meat (*Callinectes sapidus*)	4	21.1	.1028	.0336	.2052	.002262	.001582	.000042
Blue crab, claw meat	3	20.4	.0706	.0345	.1796	.000746	.000368	.000015

[a] Samples first dried on steam bath and finished in electric air oven at 80° C.

Source: Nilson, H. W., and Coulson, E. J., "The Mineral Content of the Edible Portions of Some American Fishery Products," U. S. Bureau of Fisheries, *Investigational Rept.*, **41** (1939).

Their figures indicate that oysters, shrimp, and crabs contain approximately half as much calcium, five times as much magnesium, and more phosphorus than an equal quantity of milk. In addition these shellfish and Crustacea are particularly good sources of iron, copper, and iodine.

Composition of Roe. No complete analyses of the roe of marine fishes are to be found. Atwater's analysis of shad roe is as follows: Water 71.25 per cent; water-free substance 28.75 per cent; fats 3.78 per cent; nonnitrogenous extractive matters 2.56 per cent; protein (N $\times$ 6.25) 20.88 per cent.

Gobley has examined the eggs of carp and determined the following substances: Water 64.08 per cent; paravitellin 14.06 per cent; fat 2.57 per cent; cholesterol 0.27 per cent; lecithin 3.04 per cent; extractive matters 0.39 per cent; coloring matters 0.03 per cent; inorganic matter 0.82 per cent.

Greene (1921), who followed the chemical development of the ovaries of the king salmon during the spawning migration, concluded that the mature ova have a high content of protein. The protein is at least 70 per cent higher than the yolk of the hen's egg, but on the other hand the lecithins and neutral fats are less than half the amount stored in the yolk of the hen's egg. Greene's analysis of mature salmon ova is given in Table 77.

TABLE 77. COMPOSITION OF SALMON EGGS.

	Total Per Cent	Water-free basis Per Cent	Fat-free basis Per Cent
Water	57.68	—	65.60
Solids	42.32	—	34.40
Proteins	26.66	63.01	30.33
Phospholipids	1.5	3.5	1.7
Neutral fats	12.1	28.5	—
Ash	0.66	1.56	0.75

Source: Greene, C. W., "Chemical Development of the Ovaries of the King Salmon During the Spawning Migration," *J. Biol. Chem.*, 48, 59–71 (1921).

Nutritive Value

Digestibility. Experiments on the digestibility of the protein of the edible portions of fish by human subjects have indicated that from 90 to 96 per cent is usually digested. The fat of fish is oily and usually easily and completely digested. Holmes (1918) found that the digestibility of the fat of fatty fish varied from 86.4 to 95.2 per cent.

Nutritive Value for Growth. Lanham and Lemon (1938) compared the proteins from the edible portion of nine fishery products at a level of 9 per cent by weight in the basal diet of rats. They found no practical differences in apparent digestibility but noted that the proteins fell approximately into the following groups, according to the relative growth-promoting value:

100	90	80	63
Oyster	Pilchard	Shad	Beef
	Red snapper	Cod	
	Shrimp	Croaker	
	Boston mackerel	Silver salmon	

Beveridge (1947) has recently determined the biological values of the crude flesh proteins of fillets of ling cod, halibut, lemon sole, white spring salmon, red snapper, and herring, and compared the results with data similarly obtained for egg albumin and beef. The growth of rats brought about by the fish-flesh proteins

(Courtesy U. S. Fish and Wildlife Service)

Fig. 14–2. The rate in the gain in weight of young albino rats fed on experimental diets is used as an indication of the nutritive value of fish and shellfish.

corrected for varying food intake were shown to be significantly greater than that brought about by either albumin or beef proteins.

Results indicating high nutritive value of proteins of fish and shellfish for growth of animals are to be expected since these proteins are "complete" in that they contain all of the essential amino acids (p. 291).

Vitamin Content. Fish as a class are a good source of vitamins A and D and a fair source of thiamine, riboflavin, and niacin. Data, obtained by Bailey (1942), indicating the vitamin and other nutritive values of certain Canadian fishery products, are presented in Table 78 (p. 299).

Sautier (1946) determined the thiamine and riboflavin content of a considerable number of fish and shellfish taken in the waters of southeastern Alaska. His data are given in Table 79 (p. 300). He also examined roe, milt, liver, and various other parts of a number of different fishes for thiamine and riboflavin content. These data indicated a high riboflavin content in the roe, milt, and liver; however, the thiamine content of these organs was only slightly higher than the flesh of the fish from which these products were obtained. Goldbeck (1947) also studied the thiamine content of many fishery products. Her data are presented in Tables 80 and 81 (p. 301).

Relatively little work has been carried out on the vitamin content of cooked fishery products. The meager data available are of importance since most fishery products are eaten after they have been cooked. Martinek and Goldbeck (1947), who studied the thiamine, riboflavin, and niacin content of baked croaker fillets, noted a 17 per cent loss of thiamine and approximately a 10 per cent loss of rioboflavin and niacin during baking (Table 82, p. 302).

TABLE 78. NUTRITIVE VALUES OF BRITISH COLUMBIA FISHERY PRODUCTS.

	Protein	Oil or Fat	Carbohydrates	Energy Value	Vitamin A	Vitamin B_1	Riboflavin	Nicotinic Acid	Vitamin D	Calcium	Phosphorus	Iodine	Iron	Copper
	(%)	(%)	(%)	Cals/lb	USP units/lb	mg/lb	mg/lb	mg/lb	I.U./lb	mg/lb	mg/lb	mg/lb	mg/lb	mg/lb
Halibut, fresh or frozen	23.5	4.5	—	625	2,000	0.40	0.80	27.0	200	60	1,150	—	3.0	0.3
Herring, fresh or frozen	14.5	10.5	—	720	450	0.20	0.50	16.0	1,430	—	—	—	7.0	—
Herring														
canned in tomato sauce	17.6	11.2	—	800	500	—	0.50	16.0	1,500	—	1,100	—	—	—
Pilchards, canned	16.2	14.9	—	930	0	—	—	—	3,380	1,350	1,250	—	—	0.5
Salmon														
Spring, Red or White														
fillets fresh or frozen	20.0	12.5	—	910	350–2,500	—	—	—	2,000	—	1,150	0.13	—	—
Sockeye, canned	20.0	9.3	—	770	30–800	tr.	1.0	27.0	2,000	1,050	1,300	0.20	5.9	1.0
Coho, Canned	21.0	8.0	—	720	—	—	—	—	1,200	1,300	1,350	0.12	—	0.4
Coho (Blueback)														
dressed, fresh or frozen	20.0	4.5	—	560	—	—	—	—	700	—	—	—	—	—
Pink, canned	19.5	6.4	—	630	0–450	—	—	—	1,500	850	1,200	0.15	—	0.6
Chum, canned	21.5	5.0	—	610	0–130	—	—	—	1,000	—	—	0.10	—	—
Steelhead, dressed														
fresh or frozen	21.0	11.0	—	860	—	—	—	38.0	—	—	—	—	—	—
Smelts, fresh or frozen	18.7	1.3	—	400	—	—	—	—	—	—	—	—	—	—
Sole, Flounder														
fresh or frozen	17.4	0.7	—	350	—	0.4	—	—	—	500	1,200	—	4.0	—
Clams, canned	9.0	1.7	1.7	270	—	—	—	5.0	14.0	—	—	—	—	0.0
Oysters, fresh	9.4	2.2	3.8	340	—	—	—	3.0	—	—	—	0.17	28.0	5.6
Crabs, canned	16.2	1.2	—	350	—	—	—	13.0	—	—	—	0.15	—	1.1
Shrimp, canned wet pack	8.3	0.7	—	180	—	—	—	1.5	—	—	—	0.04	—	2.5
Shrimp, canned dry pack	8.3	0.7	—	440	—	—	—	3.5	—	—	—	0.10	—	6.0

Source: Bailey, B. E., "Chart of the Nutritive Values of British Columbia Fishery Products," Fisheries Research Board of Canada, *Prog. Repts. Pacific Coast Stations*, 53, 9–11 (1942).

Notes: (—) indicates no data as yet available. Protein calculated as (Nitrogen X 6.25). All values may vary; averages only given. Calories calculated as (% Protein X 18.6) (% Fat X 42.2) (% Carbohydrate X 18.6)

Tr.—trace mg.—milligrams I.U.—International Units USP—United States Pharmacopoeia

TABLE 79. THE THIAMINE AND RIBOFLAVIN CONTENT OF THE EDIBLE FLESH OF FISHERY PRODUCTS OF SOUTHEASTERN ALASKA.

Common Name	Scientific Name	Thiamine content [a] micrograms per 100 g		Riboflavin content [b] micrograms per 100 g	
		Range	Average	Range	Average
Clams:					
butter	*Saxidomus giganteus*	138–140	139	246–292	269
cockle	*Cardium corbis*	68–69	69	150–162	156
horse	*Schizothaerus nuttalli*	127–129	128	96–100	98
little neck	*Paphia staminea*	73–77	75	170–178	174
mud	*Mya arenaria*	78–80	79	221–265	234
Cod:					
gray	*Gadus macrocephalus*	90–94	92	141–170	158
ling	*Ophiodon elongatus*	36–62	49	28–50	39
kelp	*Hexagrammos octogrammus*	100–110	105		44
Crab, dungeness	*Cancer magister*	170–182	176	16–24	20
Eulachon	*Thaleichthys pacificus*	30–40	35		43
Flounder:					
arrow-tooth halibut	*Atheresthes stomias*		60		52
Dover sole	*Microstomus pacificus*		59		57
English sole	*Parophrys vetulus*	60–64	62	32–60	44
flathead sole	*Hippoglossoides classodon*	40–42	41	48–53	51
petrale sole	*Eopsetta jordani*		68		49
rex sole	*Errex zachirus*		38		47
rock sole	*Lepidopsetta bilineata*		62		37
starry flounder	*Platichthys stellatus*		58		43
Halibut	*Hippoglossus hippoglossus*	30–82	45	36–62	47
Halibut cheeks			58		98
Herring	*Clupea pallasii*	11–40	23	181–272	217
Mussels	*Mytilis edulis*		162		249
Octopus	*Octopus bimaculatus*	2–48	25		40
Rockfish:					
black	*Sebastodes* species	78–83	81	123–182	153
brown	*Sebastodes* species		29		90
red	*Sebastopyr ruberrimus*	42–73	55	72–132	111
Sablefish	*Anoplopoma fimbria*	105–120	113	77–98	88
Salmon:					
red	*Oncorhynchus nerka*	140–155	148	40–90	72
pink	*Oncorhynchus gorbuscha*	139–150	143	36–68	46
chum	*Oncorhynchus keta*	73–84	80	48–72	59
silver	*Oncorhynchus kisutch*	84–90	87	90–123	109
king	*Oncorhynchus tschawytscha*	92–109	101	152–256	231
Shrimp:					
pink	*Pandalus borealis*		57		142
sidestripe	*Pandalopsis dispar*		47		133
Trout:					
cutthroat	*Salmo clarkii*		56		93
Dolly Varden	*Salvelinus malma*	60–62	61	37–38	38
rainbow	*Salmo irideus*		76		203
steelhead	*Salmo gairdnerii*		75		200

[a] Sautier, P. M., "Thiamine Assays of Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **8**, No. 2, 17–19 (1946).

[b] "Riboflavin Assays of Fishery Products," *Ibid*, **8**, No. 3, 19–21 (1946).

TABLE 80. DATA ON THE THIAMINE CONTENT OF SOME FISHERY PRODUCTS.

Fishery Product	Thiamine per 100 g of Edible Portion Micrograms
Fresh or frozen:	
Anglerfish (*Lophius piscatorus*)	25
Burbot (*Lota maculosa*)	450–460
Cod (*Gadus morhua*)	40–50
Croaker (*Micropogon undulatus*)	155
Haddock (*Melanogrammus aeglefinus*)	100
Grouper, black (*Garrupa nigrita*)	160–180
Herring, lake (*Leucichthys artedi*)	100–115
Mackerel:	
Boston (*Scomber scombrus*)	170–200
King (*Scomberomorus regalis*)	50–60
Spanish (*Scomberomorus maculatus*)	160–200
Mullet (*Mugil,* species)	55
Muttonfish (*Lutianus analis*)	40
Pompano (*Trachinotus,* species)	400–425
Salmon, red (*Oncorhynchus nerka*)	125–135
Sea Robin (*Prionotus* species)	80–100
Shark, dogfish (*Squalus acanthias*)	50
Skate (*Raja,* species)	20–30
Snapper:	
Gray (*Lutianus griseus*)	170
Red (*Lutianus blackfordii*)	170–180
Swellfish (*Spheroides maculatus*)	50
Crab, blue (*Callinectes sapidus*)	75
Cooked:	
Salmon, red, baked	85–90
Crab, blue, hardshell	60
Crab, blue, softshell	85–100
Canned:	
Crab, blue, white meat	none
Salmon, pink	25

Source: Goldbeck, C. G., "Some Studies on the Content of Thiamine and Antithiamine Factor in Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **9,** No. 8, 13–21 (1947).

TABLE 81. THIAMINE CONTENT OF OYSTERS.

State	Thiamine per 100 g of raw oysters Micrograms
Louisiana	110–130
Georgia	98–106
Virginia	100–110
Maryland	100–103
New York	170–180
Connecticut	170

Source: Goldbeck, C. G., "Some Studies on the Content of Thiamine and Antithiamine Factor in Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **9,** No. 8, 13–21 (1947).

TABLE 82. DATA ON THE THIAMINE, RIBOFLAVIN, AND NIACIN CONTENT OF BAKED CROAKER FILLETS.

Lot	Baking temp. (F)	Dry-matter content (%)	Serving portion [a] (g)	mg per 100 g Baked Sample Thiamine	Riboflavin	Niacin	mg per 100 g Dry-Matter Basis Thiamine	Riboflavin	Niacin
1	375	37.8	69	0.136	0.090		0.360	0.235	
	500	32.5	80	0.168	0.100		0.516	0.307	
2	375	28.9	90	0.121	0.150		0.417	0.517	
	500	26.4	99	0.126	0.150		0.477	0.568	
3	raw	17.2	151	0.081	0.100	5.5	0.470	0.581	31.8
	375	19.5	134	0.076	0.102	5.5	0.390	0.523	28.2
	500	20.9	125	0.081	0.109	5.9	0.387	0.521	28.3

[a] Value calculated on the basis that one-third pound of raw fillet equals a serving portion and that the dry-matter contents of the raw fish in each of the three lots were equal.

Source: Martinek, W. A., and Goldbeck, C. G., "Nutritive Value of Baked Croaker," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **9**, No. 4, 9–13 (1947).

In a study of the losses of thiamine and riboflavin which occur during the cooking of oysters Marks and Nilson (1946) found that baking caused a loss of approximately 30 per cent of the thiamine content; however, simmering caused little if any loss of either thiamine or riboflavin.

Summary

In conclusion the present knowledge concerning the nutritive value of fish may be summarized as follows: Most species of marine fish vary in fat content with the season, the abundance of food, and the state of development of the sex organs. Certain species of fish, such as mackerel and herring, are very fat at certain times and lean at others; while other species, such as cod and haddock, are always of low fat content. The amino acids making up the proteins of fish muscle are the same as those of chicken muscle, and they are present in approximately the same proportions.

The proteins and fat in fish are easily digested and compare favorably in this regard with those of beef muscle. Moreover, the coagulable proteins of fish flesh have been shown to possess as valuable nutritive properties as those of beef muscle. Fatty fish are good sources of vitamins A and D.

Fish contain relatively large amounts of phosphorus which may be of value in nutrition. They are also fair sources of thiamine, riboflavin, and niacin. Marine fish contain an appreciable amount of iodine. Mollusks and Crustacea are among the foods richest in iodine. Oysters and other shellfish contain much copper which has nutritional value.

REFERENCES

Almy, L. H., "Method for the Estimation of Hydrogen Sulfide in Proteinaceous Food Products," *J. Am. Chem. Soc.*, **47**, 1381–1390 (1925).

Anderson, D. W., Jr., and Fellers, C. R., "Some Aspects of Trimethylene Formation in Swordfish," *Food Technology*, 3, 271–273 (1949).

Atwater, W. O., "The Chemical Composition and Nutritive Values of Food Fishes and Aquatic Invertebrates," *U. S. Fish Comm. Rept.*, **1888**, 679–868 (1892).

Bailey, B. E., "Nutritive Value of Marine Products. V. The Vitamin A Content of Ling Cod Liver Oil. Preliminary Note," *Contrib. Can. Biol. Fisheries,* 7, 407–412 (1933).

Bailey, B. E., "Nutritive Value of Marine Products. VI. Vitamin A Potency of Salmon Liver Oil," *Contrib. Can. Biol. Fisheries,* 8, No. 21, 267–274 (1939).

Bailey, B. E., "Nutritive Value of Marine Products. VII. The Vitamin A and D Potency of the Oils from British Columbia Canned Salmon," *J. Biol. Bd. Can.,* 2, 431–437 (1936).

Bailey, B. E., "Chart of the Nutritive Values of British Columbia Fishery Products," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* 53, 9–11 (1942).

Benson, R. L., and Wells, H. G., "A Study of Autolysis by Physio-chemical Means," *J. Biol. Chem.,* 8, 61–76 (1911).

Beveridge, J. M. R., "The Nutritive Value of Marine Products. XVI. The Biological Value of Fish Flesh Proteins," *J. Fisheries Research Board Canada,* 7, No. 1, 35–49 (1947).

Beveridge, J. M. R., "Nutritive Value of Marine Products. XVII. Value of B-Vitamins in Fish Flesh for Growth of Young Rats," *J. Fisheries Research Board Canada,* 7, No. 2, 74–87 (1947).

Bucher, G. C., Sanford, F. B., and Miyauchi, D. T., "Estimations of Extinction Ratios and Vitamin A Potency of 12 Reduction Plant Oils," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* 9, No. 7, 15–17 (1947).

Butler, C., "Vitamin A and D in Fish Livers and Viscera," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* 8, No. 4, 13–19 (1946).

Carter, N. M., "Nutritive Value of Marine Products. VIII. Proximate Analysis of Canned British Columbia Sockeye and Pink Salmon," *J. Biol. Board Canada,* 2, 439–455 (1936).

Castell, C. H., and Anderson, G. W., "Bacteria Associated with Spoilage of Cod Fillets," *J. Fisheries Research Board Canada,* 7, 370–377 (1948).

Castell, C. H., Anderson, G. W., and Pivnick, H., "Relation of Bacterial Count to Quality of Cod Fillets," *J. Fisheries Research Board Canada,* 7, 378–388 (1948).

Clark, E. D., and Almy, L. H., "A Chemical Study of Food Fishes," *J. Biol. Chem.,* 23, 483–498 (1918).

Clark, E. D., and Almy, L. H., "A Chemical Study of Frozen Fish in Storage for Long and Short Periods," *Ind. Eng. Chem.,* 12, 656–663 (1920).

Clough, R. W., "Biochemical Study of Pacific Coast Salmon with Particular Reference to the Formation of Indole and Skatole during Decomposition," *Pubs. Puget Sound Biol. Sta.,* 3, 195–272 (1922).

Coulson, E. J., Remington, R. E., and Lynch, K. M., "Studies on the Metabolisms of Copper," U. S. Bureau of Fisheries, *Investigational Rept.,* 23 (1934).

Crooks, G. C., and Ritchie, W. S., "A Study of the Rate of Decomposition of Haddock Muscle at Various Temperatures as Indicated by Ammonia Content," *Food Research,* 3, 589–598 (1938).

Crooks, G. C., and Ritchie, W. S., "Seasonal Variation in Chemical Composition of Common Haddock," *Food Research,* 4, 159–172 (1939).

Darling, D. B., and Nilson, N. W., "Nutritive Value of the Protein of Swellfish," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* 8, No. 8, 10–11 (1946).

Davidson, F. A., and Shostrom, E. O., "Physical and Chemical Changes in the Pink Salmon During the Spawning Migration," U. S. Bureau of Fisheries, *Investigational Rept.,* 33 (1935).

Dyer, F. E., and Dyer, W. J., "Changes in the Palatability of Cod Fillets," *J. Fisheries Research Board Canada,* 7, 449–460 (1949).

Farber, L., "Chemical Evaluation of Odor Intensity," *Food Technology,* 3, 300–304 (1949).

Fellers, C. R., Shostrom, O. E., and Clark, E. D., "Hydrogen Sulfide Determination in Bacterial Cultures and Certain Canned Foods," *J. Bact.*, **9**, 235–249 (1924).

Finn, D. B., "Nutritive Value of Marine Products. IV. A Note on the Vitamin A Content of Commercial Pilchard Oil," *Contrib. Can. Biol. Fisheries*, **6** (N.S.), 357–363 (1931).

Finn, D. B., "Denaturation of Fish Muscle Proteins by Freezing," *Contrib. Can. Biol. Fisheries*, **8**, 313–320 (1934).

Fitzgerald, G. A., and Nettleton, B. E., "Have You Overlooked Fish?" *Hospital Management*, **52**, No. 2, 40–43 (1941).

Gibbons, N. E., and Reed, G. B., "Effect of Autolysis in Sterile Tissue on Subsequent Bacterial Decomposition," *J. Bact.*, **19**, 73–88 (1930).

Goldbeck, C. G., "Some Studies on the Content of Thiamine and Antithiamine Factor in Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **9**, No. 8, 13–21 (1947).

Greene, C. W., "Chemical Development of the Ovaries of the King Salmon During the Spawning Migration," *J. Biol. Chem.*, **48**, 59–71 (1921).

Holmes, A. D., "Experiments on the Digestibility of Fish," *U. S. Dept. Agr. Bull.*, **649** (1918).

Jones, D. B., "The Nutritional Value of Oysters and Other Seafoods," *Am. J. Pub. Health*, **16**, 1177–1182 (1926).

Kik, M. C., and McCollum, E. V., "The Nutritive Value of Haddock and Herring," *Am. J. Hyg.*, **8**, 671–693 (1927).

Lang, O. W., Farber, L., and Yerman, F., "The 'Stinkometer'—New Tool," *Food Industries*, **17**, No. 1, 78–79, 186–188 (1945).

Lanham, W. B., Jr., and Lemon, J. M., "Nutritive Value for Growth of Some Proteins of Fishery Products," *Food Research*, **3**, 549–553 (1938).

Lee, C. F., and Nilson, H. W., "Study of the Metabolism of Naturally Occurring Fluorine in Canned Salmon and Mackerel," U. S. Bureau of Fisheries, *Investigational Rept.*, **44** (1939).

Lemon, J. M., and Truitt, R. V., "Seafood and the Diet," *Chesapeake Biol. Lab. Pub.*, **42** (1941).

Lucke, F., and Geidel, W., "Determination of the Volatile Basic Nitrogen of Fish as a Measure of Their Freshness," *Ztschr. f. Untersuch. Lebensm.*, **70**, 441–458 (1935).

Manning, J. R., "Fish and Shellfish for Food," U. S. Bureau of Fisheries, *Special Memo*, **2256B** (1935).

Marks, A. L., and Nilson, H. W., "Effect of Cooking on the Nutritive Value of the Protein of Cod," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **8**, No. 12, 1–6 (1946).

Marks, A. L., and Nilson, H. W., "Thiamine and Riboflavin in Baked and Simmered Oysters," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **8**, No. 12, 12–13 (1946).

Martinek, W. A., and Goldbeck, C. G., "Nutritive Value of Baked Croaker," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **9**, No. 4, 9–13 (1947).

Newell, J. M., and McCollum, E. V., "Spectrographic Analysis of Marine Products," U. S. Bureau of Fisheries, *Investigational Rept.*, **5** (1931).

Nickerson, J. T. R., Goldblith, S. A., and Proctor, B. E., "A Comparison of Chemical Changes in Mackerel Tissues Treated by Ionizing Radiation," *Food Technology*, **4**, 84–88 (1950).

Nickerson, J. T. R., and Proctor, B. E., "Some Chemical Changes Exhibited in Sterile and in Contaminated Haddock Muscle Stored at Different Temperatures," *J. Bact.*, **30**, 383–394 (1935).

Nilson, H. W., and Coulson, E. J., "The Mineral Content of the Edible Portions of Some American Fishery Products," U. S. Bureau of Fisheries, *Investigational Rept.*, **41** (1939).

Nilson, H. W., Martinek, W. A., and Jacobs, B., "Nutritive Value for Growth of Some Fish Proteins," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **9,** No. 7, 1–7 (1947).

Okuda, Y., "Quantitative Determination of Creatin, Creatinine and Monoaminoacids in Certain Fishes, Mollusca and Crustacea," *J. Coll. Agr. Tokyo Imp. Univ.,* **5,** 25–31 (1912–16).

Okuda, Y., "Chemistry of 'Chiai' Flesh," *J. Coll. Agr. Tokyo Imp. Univ.,* **7,** 1–28 (1919).

Okuda, Y., Okimoto, T., and Yada, T., "Hydrolysis of the Muscle Proteins of the Whale and the Cod," *J. Coll. Agr. Tokyo Imp. Univ.,* **7,** 29–37 (1919).

Okuda, Y., and Oyama, K., "Hydrolysis of Fish Muscle," *Am. J. Physiol.,* **23,** 81–89 (1908).

Osborne, T. B., and Heyl, F. W., "Hydrolysis of Fish Muscle," *Am. J. Physiol.,* **23,** 81–89 (1908).

Parks, T. B., and Rose, E. R., "Copper, Iron, and Manganese Content of Fish," *J. Nutr.,* **6,** 95–98 (1933).

Peterson, W. H., and Elvehjem, C. A., "The Iron Content of Plant and Animal Foods," *J. Biol. Chem.,* **78,** 215–223 (1928).

Pottinger, S. R., and Baldwin, W. H., "The Content of Certain Amino Acids in Seafoods," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **8,** No. 8, 5–9 (1946).

Proctor, B. E., Nickerson, J. T. R., and Goldblith, S. A., "Effect of Refrigerated Storage at Various Temperatures on Chemical and Bacterial Contents of Haddock," *Refrig. Eng.,* **58,** 375–379 (1950).

Reay, G. A., "The Spoilage of Fresh Fish and Its Control," *Chem. and Ind.,* **1949,** 35–39.

Riddell, W. A., "Nutritive Value of Marine Products. XI. Proximate Analysis of Canned British Columbia Coho (Blueback) Salmon," *J. Biol. Board Canada,* **2,** 463–468 (1936).

Riddell, W. A., "Nutritive Value of Marine Products. XII. Mineral Constituents of Some Food Fishes of British Columbia," *J. Biol. Board Canada,* **2,** 469–472 (1936).

Riddell, W. A., "Nutritive Value of Marine Products. XIII. Mineral Constituents of the Flesh, Skin, Bone, and Free Liquor in Canned British Columbia Coho (Blueback) Salmon," *J. Biol. Board Canada,* **2,** 473–475 (1936).

Sanford, F. B., Miyauchi, D., and Jones, G. I., "Studies on Deterioration of Vitamin A in Fish Livers and Liver Oils. Part I, Loss of Vitamin A and Stability in Grayfish Livers in Storage," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **9,** No. 2, 11–15 (1947).

Sautier, P. M., "Thiamine Assays of Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **8,** No. 2, 17–19 (1946).

Sautier, P. M., "Riboflavin Assays of Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **8,** No. 3, 19–21 (1946).

Stansby, M. E., "Judging the Quality and Freshness of Fish by Organoleptic Methods," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **94** (1944).

Stansby, M. E., and Lemon, J. M., "Studies on the Handling of Fresh Mackerel," U. S. Fish and Wildlife Service, *Research Rept.,* **1** (1941).

Stansby, M. E., and Lemon, J. M., "An Electrometric Method for the Detection of Relative Freshness of Haddock," *Ind. Eng. Chem. Anal. Ed.,* **5,** 208–211 (1933).

Tarr, H. L. A., and Ney, P. W., "Effect of Flesh Acidity on Bacterial Numbers and Trimethylamine in Spoiling Fish," Fisheries Research Board Canada, *Prog. Repts. Pacific Coast Stations,* **11,** No. 78, 11–13 (1949).

Tillmans, J., and Otto, R., "Detection of Incipient Decay in Fish," *Ztschr. f. Untersuch. Lebensm.,* **47,** 25–37 (1924).

Tillmans, J., Hirsch, P., and Kuhn, A., "The Chemical and Physico-chemical Changes Occurring in the Incipient Spoilage of Meat," *Ztschr. f. Untersuch. Lebensm.*, **53,** 44–64 (1927).

Tressler, D. K., "Some Considerations Concerning the Salting of Fish," U. S. Bureau of Fisheries *Doc.*, **884** (1920).

Tressler, D. K., and Wells, A. W., "Iodine Content of Sea Foods," U. S. Bureau of Fisheries *Doc.*, **967** (1924).

Tully, J. P., "Nutritive Value of Marine Products. XIV. Proximate Analyses of Fresh British Columbia Oysters," *J. Biol. Board Canada,* **2,** 477–484 (1936).

Watson, V. K., and Fellers, C. R., "Nutritive Value of the Blue Crab (*Callinectes sapidus*) and Sand Crab (*Platyonichus ocellatus latreille*)," *Trans. Am. Fisheries Soc.,* **65,** 342–349 (1935).

White, F. D., "Nutritive Value of Marine Products. IX. Proximate Analysis of British Columbia Canned Pilchard," *J. Biol. Board Canada,* **2,** 457–460 (1936).

White, F. D., "Nutritive Value of Marine Products. X. Proximate Analysis of Ling Cod," *J. Biol. Board Canada,* **2,** 461–462 (1936).

Yamada, K., and Kitano, E., "On the Relation Between the Freshness of Fish Meat and the Change of Electric Resistance," *Contributions from the Central Fisheries Station of Japan,* 32 (1946–1947), 232–236 (1948).

CHAPTER 15

Transportation of Fishery Products

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Introduction

Since the turn of the century man's knowledge of the sciences has tremendously increased, resulting in a great advance in the general standard of living. In this age man has become largely independent of temperature, climate, and season, not only as regards his physical comforts, but also his daily menu. Therefore, the traveller of today expects orange juice for breakfast, fish for luncheon and dinner, and fresh fruits and nuts at the finish of the meal no matter where he may be, or what the time of year. These not unreasonable expectations stem from the great strides made in food technology in the past several decades. Indeed, we are now accustomed to the colorful and attractive displays of fresh and frozen foods in the modern food markets; if we do not see what we want, we ask for it with some degree of petulance and the feeling that the market is not quite complete. We often overlook the difficulties that must be overcome to grant us our desires in "off" seasons.

The seasonal nature of fishery operations makes the supply of all types throughout the year rather difficult. Habits of the fish, vagaries of the elements, and national and international regulations impose tremendous variations in the "catch" of many species, and these, in turn, induce processing, handling, and storage difficulties. Added to these, man's propensity for dispersing his populations over wide areas causes serious transportation problems. These difficulties have been and still are the subject of much thought and experimentation, and a complete account of all the work done on them is beyond the scope of this volume. However, in this chapter the present means of transporting commercial fishery products by sea, land, and air are briefly considered. Special emphasis will be placed on the requirements of the products and an attempt made to show in what ways the present facilities are lacking in some of the requirements and how they might be improved.

Before considering the existing transportation facilities for fish, however, it might be profitable to consider briefly the requirements for ideal storage of both unfrozen and frozen fishery products, since technically, at least, transportation of these products is only modified storage. An examination of the recommendations of fishery technologists shows that there are three main requirements for the ideal storage of fresh (unfrozen) fishery products: (1) A constant temperature just slightly above the initial freezing point of the product to reduce bacterial and enzymic activity to a minimum; (2) an atmosphere saturated with water vapor,

immediately surrounding the product, to prevent desiccation; (3) an atmosphere free from oxidizing or volatile compounds which might induce "off" flavors in the product.

For economic reasons any facility, to be practicable, must be readily available and inexpensive. Hence, water ice has long been thought of as an ideal substance for the holding of unfrozen fishery products; however, it does not entirely fulfill the above requirements. In the first place its melting point is several degrees above the initial freezing point of most fishery products; and secondly, the ice, in melting, produces water which, if permitted to come in direct contact with the product, has a leaching effect which may detract from the appearance and flavor of the products.

Most authorities agree that frozen fishery products should be stored at sub-zero temperatures, the exact temperature depending upon the proposed storage life of the product. Also, to prevent the product from disiccating and oxidizing, the atmosphere surrounding it should be saturated with water vapor and free from oxidizing agents.

In order to make the transportation service economically sound the commercial carriers must have the necessary flexibility in their facilities to accommodate all commodities. The temperature requirements for general purpose storage do not impose a particularly difficult problem. Modern control equipment is readily available, whereby temperatures within the range -20 to $55°$ F (-28.9 to $12.8°$ C) can be easily maintained within the necessary limits.

The control of humidity would be equally simple if fish alone were to be considered; but in the shipment of fruits and vegetables the relative humidity should not vary beyond limits determined by the need to restrict evaporation on the one hand and the growth of molds and bacteria on the other. If the refrigeration system can maintain a relative humidity in the neighborhood of 85 per cent it may be regarded as adequate in the light of present knowledge.

The control of the atmosphere, as in the "gas storage" of fruit or chilled meat in a certain concentration of carbon dioxide, presents a somewhat more complex problem, particularly in regard to the shipment of "living" biological materials, such as fruits, which respire and thus generate heat as well as carbon dioxide. However, attempts are being made to control the atmosphere as well as temperature in cold storage rooms, and the following section will give a brief description of such a scheme.

The Jacketed System

In a refrigerated space (hold of a vessel, railway car, truck, etc.) filled with frozen fish heat leakage through the walls, floor, and ceiling into the space constitutes the principal refrigeration load since the load does not generate heat. On the other hand if the same space is occupied by fruit, the heat generated by the load may be of the same order as that coming through the insulation, or it may be many times the heat leakage if the fruits have not been precooled. The two heat loads vary in proportion with the temperature of the fruit. Since the two thermal loads vary so much in their relative proportions and since they must be removed, one from the outside, the other from the inside of the space, it is reasonable to arrange the refrigerating system so that they are separately dealt with as far as practically feasible.

The separation of leakage heat from cargo heat has an important bearing on the control of both temperature and relative humidity. A common air-stream which has to take up heat from both sources will naturally undergo a greater temperature rise than if it had to absorb heat from the cargo only; therefore, there would be a greater temperature variation from side to side of the cargo stack. An air-stream passing through fruit tends to reach equilibrium through a balance between the heat given off and the water lost by the fruit. On passing through meat, fish, or other materials which do not generate heat, but which do evaporate water, it tends towards complete saturation. In either case if the air-stream has to deal with leakage heat as well as cargo heat, the relative humidity will be lowered. This may or may not be an advantage, but in any case it is uncontrolled. In certain instances, for example where frozen fish are stored, it is of such importance as to have led to the use of the jacketed system of cooling, designed essentially to overcome the difficulty of excessive desiccation.

Most of the present cooling systems constitute uncontrolled approximations to the ideal of a separation of the two sources of heat. In the grid system the side grids primarily absorb the heat from the walls and floor, while the ceiling grids deal with the heat from the cargo and that coming through the roof. In the battery system a partial short-circuiting of some air around the cargo stack deals with the leakage heat, while the rest of the air penetrates and removes the heat from the cargo. Since in both cases the separation is partial and uncontrolled, some of the leakage heat may gain access to the cargo before being absorbed by the cooling pipes.

A complete separation of function requires the provision of an interior lining to the room so that the cargo is surrounded by a "jacket" in which the leakage heat is removed. The cooling of the cargo and the jacket can then become separate problems. In the jacketed space the degree of air circulation can be made a function of the amount of heat generated there and the relative humidity desired. If no heat is released in this space, then usually no circulation is necessary. If the jacket is practically gas tight, then the space will become saturated with water vapor evaporated from the product, and no further desiccation can take place. However, if circulation is required, then, wherever practicable, it should be vertical rather than lateral, since in the latter case the superposition of convective flow on the forced movement may result in an uneven temperature distribution. The cooling of the jacket itself is best accomplished by circulating through it air which is cooled in an external cooler. The circulation of the cooling air through the cargo and the jacket may be induced by a single fan system, either in parallel or series flow; but the parallel flow is preferable since in this scheme the common air-stream can be divided in any predetermined ratio, depending upon the type and demands of the cargo, by means of a suitable adjustable or automatic proportioning device.

The principle of the jacket has general application in cold storage and transportation services, particularly in the holds of refrigerated ships where space is at a premium. Through careful design the jacket may be reduced to minimum dimensions for the uptake of the maximum leakage load, and the cargo space can be correspondingly increased. This increase in loadable space may or may not result in higher cost. The cost of the jacket may be partially or entirely offset by the saving in piping due to both higher heat-transfer and the shorter length

of leads, and the extra cost of fan power may be offset by possible economies in dunnage materials. These are factors that require careful study by designers and practical engineers. It does seem clear, however, that the jacketed system can be made sufficiently flexible to cope with the demands for the various cargoes without duplication of equipment and that it will result in better control of temperature, humidity and carbon dioxide content with little or no increase in cost.

It is expected of the carrier of perishable comestibles that the products be transported with no more change or effect on its keeping qualities than would have taken place had the products not been removed from storage. That is to say, the conditions that prevail in storage should prevail during the transportation episode. Therefore, the problems confronting the carrier of fish are the same as those of the storage operator, with the added complication that his facilities must transport the fish as well. Transport facilities are not generally as complete and desirable as the corresponding stationary storage facilities, probably because a greater tolerance is permitted as a result of the mobile requirement. This fact could also be due to failure to emphasize the importance of maintaining low and constant temperatures, until recently not recognized as being essential. It is encouraging to find, however, that in the past decade much has been done to bring the conditions in carrying means more in line with the storage conditions maintained in stationary plants. This may indicate that all the requirements will soon be met both technically and economically.

Transportation by Sea

The application of refrigeration on ships has lagged only slightly behind that on land installations. As early as 1879 frozen meat was carried from Australia to Great Britain on the "Strathleven," a ship refrigerated with a cold-air machine. For safety reasons cold-air machines were used rather than ammonia, but they were later replaced by carbon dioxide machines because of their somewhat greater flexibility. The heavy and rather inefficient carbon dioxide equipment, in turn, has given way to "Freon-12," which is now generally accepted as one of the least hazardous and most efficient ship refrigerants.

Apart from limitations of space and weight and safety regulations ship insulation can closely follow land practices. In the older ships the holds were insulated with cork mostly, but in more recent installations, particularly during and since World War II, the new lighter forms of insulation, such as glass-wool batts, have been used with good results. Of course great care must be taken with the application of any insulation on ships, particularly in the setting up of effective moisture-vapor barriers in the proper places to prevent the undesirable accumulation of frost and the possible breakdown of the insulation. Failure of insulation in the holds of vessels has almost invariably been caused by ineffective or improperly applied vapor barriers.

The methods of cooling the holds of vessels also closely follow shore-plant practice. Those holds in which unfrozen perishables are carried are usually refrigerated by the circulation of cooled air through a system of ducts. The air is cooled in a bunker, by pipe coils or a brine spray, the density of which can be controlled to give the desired humidity to the circulated air. This is sometimes referred to as the "trunk" or the "bunker" system.

Those holds in which frozen materials are carried are usually refrigerated by

pipe coils on the ceilings and walls. The pipes are cooled by the primary refrigerant ("Freon-12") or by brine. This is often referred to as the "grid" system.

All the equipment connected with the refrigeration of ships is usually of standard design for ready replacement and repair. However, all pipes, coils, fan casings, and other steel parts must be hot-dipped, galvanized, or otherwise treated to protect them from the salty atmosphere.

Transportation by Rail

Commercial fishery products are transported by rail almost entirely in insulated cars, called refrigerators or reefers in Canada and the United States. These are essentially "ice boxes on wheels," insulated with from 2 to 5½ inches of hairfelt, aluminum foil, or "Fiberglas" and cooled by means of ice or ice and salt mixtures carried in tanks suspended from the ceiling or placed in the ends of the car. Those cars with tanks along the ceiling are called overhead or roof-tank cars and those with the tanks in both ends are called end-bunker cars.

Fresh (unfrozen) fish are shipped mostly in express refrigerators of either the overhead or end-bunker types. The fish are packed in ice in boxes and the car itself is serviced with a salt and ice mixture in order to minimize the melting of the ice surrounding the fish. The concentration of salt in the mixture depends upon the season and the ambient temperature, and in no case does it completely prevent the melting of the ice around the fish. The melt from the ice carries with it slime, dissolved proteins, and salts from the fish, all of which are food for bacteria. This nutrient solution saturates the exposed parts of the interior of the car and often gains access to the insulation. As time passes decomposition sets in and gives rise to objectionable odors. Thus cars that have been used for the shipment of unfrozen fish are easily identified and are often rendered useless for other food products.

Frozen fish move mostly by freight refrigerators since they are less perishable in the frozen state and time, therefore, is a less important factor. The fish are usually boxed just before shipment, although bulk fish are also shipped, or the shipment may be mixed bulk and boxed. Before loading the car is precooled for from 12 to 24 hours with ice and salt in the proportions 30 pounds of salt to 100 pounds of ice. Some shippers use lower concentrations of salt, but this is not good practice. When the car has been properly precooled, the fish are loaded as expeditiously as possible by hand truck, conveyors, or fork trucks. After loading, the bunkers or ice tanks are "topped off" or reiced to capacity with the same proportion of ice and salt used in the precooling.

The End-Bunker Car. At present the most popular refrigerator car in the United States is the end-bunker car, of which there were about 110,000 out of a total of approximately 135,000 of all refrigerator types at the end of 1947. The size that seems to be most favored is the 40-foot car, insulated with about 3 inches of hairfelt. This car, when fitted with end bunkers and bulkheads, has a loading space approximately 34 feet long. The bunker capacity is from 5 to 7 tons of ice which is loaded through hatches in the roof. All end-bunker cars are equipped with floor racks and the walls are cleated or cross-stripped when boxed commodities are shipped to permit the circulation of air. Air circulation in these cars is longitudinal and, when induced by convection only, results in rather unequal temperatures throughout the loading space, the highest degree being in the

center at the top. Some reports indicate that differences as great as 20° F (11.1° C) have been noted between the warmest and the coldest parts of the load. The differences of temperature are greatest, naturally, when the level of the cooling mixture in the tanks is low; therefore, it is very important that the bunkers be kept as full as possible. Since the cooling mixture in the lower parts of the bunkers is relatively ineffective, in some cases the lower halves are shelved off and the upper parts only are iced. This is sometimes referred to as "stage icing" or "half-stage icing." In the United States and Canada more or less efficient icing stations have been set up at selected points so that cars can be reiced about every 24 hours in long runs.

The Fan Car. The inadequacy of the end-bunker car results from the position of the cooling tanks and the relatively long path taken by the circulating air. Since the air movement is induced by convection, the velocity is low, and consequently the rate of heat transfer to the tanks is correspondingly low. The recognition of these factors gave rise to the use of circulating fans, which may be operated by a friction drive off the wheels of the car while it is in motion or by electric motors which may be attached to the side of the car where electrical power is accessible when the car is standing still.

Fan cars have been described in many publications and their application and performances are now well-known. The reports indicate, as would be expected, that the output of the fans is a function of the speed of the train, and therefore varies considerably. The 7½-inch (Preco) fan is reported to deliver from 1,600 to 2,000 c.f.m. and to require about 1 h.p. when the car is travelling at 30 m. p. h. When these cars are stationary and the fans are not operating, their performance is similar to that of the end-bunker car without fans; therefore, their over-all efficiency depends upon the ratio of running to standing time. The use of attachable motors during the standing time, of course, improves performance, but many railway yards in the United States and Canada have no electrical outlets conveniently situated for this service. It is likely that these will be provided, however, if the fan car becomes generally accepted.

When fan cars are in motion with the fans operating, the temperatures attainable in the car are more uniform and somewhat lower than the temperatures in similar end-bunker cars, and ice meltage is correspondingly greater. The effect of the fans, however, is to make the performance less dependent upon ice level in the bunkers; consequently, the bunker capacity could be increased so that the frequency of icing would not be affected by the increased ice consumption.

The Roof-Tank Car. The illogical position of the cooling bunkers in the end-bunker cars, which resulted in poor temperature distribution, gave rise to the development of the roof-tank car, first in South Africa and more recently in Canada.

The overhead or roof-tank car now adopted as standard in Canada is 40 feet long inside and is insulated with approximately 4 inches of "Fiberglas" in the walls and ends and approximately 5 inches on the floor and ceiling. It is equipped with 8 roof tanks, holding slightly over 3 tons of ice in total and accessible through 8 hatches in the roof of the car. These tanks are equipped with brine-retaining traps, as well as drain plugs. The brine may be retained at a predetermined level within the tanks to flood the bottom completely and thus maintain a uniformly low temperature there, consistent with the concentration of the

cooling mixture used. The cars are fitted with floor racks and permanent side and end-wall flues for air circulation.

In these cars the circulation of the heat-carrying air is lateral rather than longitudinal. Because of the shorter circulation path and the logical position of the cooling tanks, lower mean and more uniform temperatures than those in the end-bunker car are attainable. Frequency of reicing is less critical and the bunkers need not be kept full as is the case with end-bunker cars. Some economy of ice is possible at the end of trips since cooling is unaffected by the quantity of the cooling medium.

Although the overhead system of cooling is more logical and effective than the end-bunker system, it is not especially favored in the United States, as it is in Canada, mainly because of the alleged increased difficulty in icing. Many American yards have special icing facilities designed specifically for end-bunker cars. The cost of any changes brought about by a new car design would necessarily include the cost of servicing facilities, and some railroad officials hold that the change-over from the end-bunker system to the overhead system is too costly.

"Dry-Ice" Cars

A number of systems employing "Dry Ice" as the refrigerant have been explored in railway cars. These vary in principle from blocks of "Dry Ice" placed in overhead tanks, the carbon dioxide gas evolved being permitted to gravitate to the floor through wall flues, to complicated control mechanisms which automatically maintain a given temperature in the car by regulating the amount of heat to gain access to the "Dry Ice."

The Broquinda System. The Broquinda system employs "Dry Ice" to cool a secondary liquid which has a low freezing point and a high coefficient of thermal expansion. The essential elements of this system consist of an insulated outer compartment which is accessible through the roof of the refrigerator car and which contains a metal "Dry-Ice" receptacle surrounded by a jacket which contains the secondary liquid. The jacket, in turn, is connected top and bottom to a system of finned coils suspended from the ceiling of the car. A regulating valve controlled by a thermostat is connected in the coil circuit. Railway cars are fitted with two such units, one situated at each end of the car, and the coils extend to the center.

The operation is very simple. "Dry Ice," placed in a special compartment through the roof hatch, cools the liquid in the jacket. This cold, dense liquid passes into the cooling coils through the lower connection and is warmed and expanded by the heat taken up within the car. The warmed, less dense liquid returns to the jacket through the upper connection and is cooled there by carbon dioxide. The rate of circulation of the secondary liquid is regulated by the valve and thermostat, and thus the temperature in the car is controlled. Since it is reported that temperatures within the car can be controlled within narrow limits (actual limits not given) and that the system can be used for shipments of fresh and frozen commodities, it could have application in the transportation of fish. Its main limitations at the moment, as far as fish are concerned, are the cost and availability of "Dry Ice."

Although the Broquinda system can be made efficient with reference to the utilization of "Dry Ice," since even the carbon dioxide gas evolved before it escapes can be brought to absorb heat from the space to be cooled, there are many centers

in the United States and Canada, from which fish are shipped, where solid carbon dioxide either is not available or its price is prohibitive for use in such a scheme.

The Dieco System. The Dieco "Dry-Ice" system for cooling railway refrigerator cars is somewhat similar to the Broquinda system. It was developed by the Dry-Ice Equipment Company of San Francisco, California, and was tried out in road tests in 1947. The main difference between the Dieco and the Broquinda systems is in the means of circulating the secondary cooling liquid. In the Dieco system this liquid is circulated by pressure generated from the gas evolved from the "Dry Ice," which is contained in a small pressure tank in the bunker chamber. The car temperature is controlled by a throttling valve in the liquid line in a manner similar to that in the Broquinda system.

The Split-Absorption System

Presumably the split-absorption system as applied to railway refrigerator cars derives its name from the fact that in this application the ordinary continuous absorption operation is "split" into two parts. In the ordinary ammonia absorption plant, it will be recalled, the evaporation, absorption, and recovery of the ammonia go on concurrently, thus making the operation continuous. In the split-absorption system the evaporation and absorption of the ammonia take place on the car and the recovery of the ammonia from the resulting strong ammonia "liquor" (concentrated water and ammonia solution) takes place in stationary recovery plants, thus making the operation intermittent.

By "splitting" the operation this way there are no "moving parts" on the refrigerator car. All that are required here are an ammonia storage tank or receiver, connected to cooling coils through a surge drum and controlling mechanism, and an absorber. The operation of this part of the system is extremely simple. Liquid ammonia is admitted through a control valve to the surge drum and the evaporator coils, where it evaporates or boils under the reduced pressure maintained by the absorber. The ammonia vapor evolved passes through the coils and is absorbed by the water in the absorber. The temperature in the car is controlled by a thermostat which regulates the flow of ammonia to the coils and the gas from the coils to the absorber through the pressure in the coils.

The Frigid Transport Corporation of the United States holds patents covering the split-absorption system on railway cars, and at the request of this corporation and the Birdseye-Snider Division of General Foods Corporation the U. S. Department of Agriculture conducted a test of a refrigerator car equipped with this system. The car tested was fitted with two ammonia storage tanks with a combined capacity of 1,900 pounds and two water tanks or absorbers with a total capacity of 750 gallons (Anon., 1947). During a ten-day observation period, a mean temperature of approximately 0° F (− 17.8° C) was maintained inside the car while the outside temperature was held at 92° F (33.3° C). A total of 11,000 pounds of ammonia, at the rate of 42 pounds per hour, and 5,000 gallons of water, at 19 gallons per hour, were used. Servicing took place at daily intervals; it involved the addition of about 1,000 pounds of liquid ammonia and the removal of the ammonia solution and its replacement with 500 gallons of fresh water each day.

The daily servicing requirements, coupled with the disposition of the strong

ammonia solution from which anhydrous ammonia must be recovered or the solution otherwise utilized, are distinct disadvantages to this system. Should it be applied generally by railway companies, recovery plants would have to be spaced throughout all railway systems so that cars could be serviced at 24-hour intervals. The plants would require, in addition to recovery equipment, adequate storage and pumping facilities, not only for the liquid ammonia, but also for the strong ammonia solution transferred, so that a number of cars could be serviced in a short time.

Mechanical Refrigerator Cars

Europe (the Altek System). The necessity for sub-zero temperatures for the holding and transport of all frozen foods, coupled with the inability of ice and salt mixtures to hold such temperatures in the standard refrigerator cars, has led to investigations with compression systems. In Europe a fairly satisfactory compression system was developed about 1937 and called the Altek system.

The essential components of this system, as used in Belgium, consisted of an 11-h.p. water-cooled Diesel engine, a two-stage air-condensing direct expansion ammonia system, a 110-volt d.c. generator, electric fans for engine cooling and air circulation through the evaporator, fuel tanks with a capacity sufficient for 7 days of operation, thermostats and control mechanism for automatic temperature control within the range 5 to 50° F (– 15 to 10° C), and electric heaters for heating the car to the required interior temperature.

It was reported that the railway cars in Europe equipped with this system were given extensive tests in 1937 and the following year; as a result negotiations were under way in 1939 to have a unit tried out in Canada, but World War II intervened.

The fate of the manufacturing company is not known; but, as evidenced by the equipment which fell into Allied hands during and at the end of hostilities, some of the principles applied in the Altek system were used by the Germans in both railway cars and trucks during the latter part of the war.

United States. A truly mechanical type of car was introduced in 1930 and tested in 1931. This car was cooled with a 1-ton compressor driven by a Diesel engine, and its operation was described as satisfactory. At that time, however, a temperature of 10° F (– 12.8° C) was considered satisfactory for frozen foods.

In the past few years the increased use of mechanical cooling of road trucks and trailers has given support to the view that similar mechanical systems are at least technically feasible in railway cars. Studies are now being conducted in both the United States and Canada to determine the economics of the various mechanical systems adaptable to railway cars.

At present in the United States two types of equipment are being studied. One is somewhat similar to the Altek system, already described, and employs a Diesel engine. This may be called a "built-in" type, for the various elements of the system (engine, generator, compressor, and evaporator) are built into the body of the car. A car of this type is being investigated jointly by the Atcheson, Topeka, and Santa Fe Railway and the Trane Company of La Crosse, Wisconsin. The other type is known as the "packaged system," in which a unit with all its elements forms a single "package" or parcel. The power for such a unit is supplied by a gasoline engine. A brief description of the parcel type will be found in the

succeeding section. A car of this type is being investigated by the Fruit Growers Express Company in collaboration with the U. S. Thermo Control Company of Minneapolis, Minnesota.

In Canada. Several new ideas relating to the mechanical cooling of railway cars are being investigated by the Fisheries Research Board of Canada in collaboration with the Canadian National and Canadian Pacific Railway Companies. The work started in 1948 when the Fisheries Research Board reconditioned an old overhead tank car loaned by the Canadian National Railways.

The Canadians were the first to apply the "packaged system" to a railway car. The experimental car is equipped with two identical packaged units, each one being capable of supplying the maximum cooling or heating load. These units are fitted into metal compartments on each side of one end of the car. Each compartment is fitted with a cradle in which the unit rests and a track which permits the unit to be pulled out of the compartment for inspection or other purposes. The units are secured in place by means of a clamping device which permits a quick exchange in case of failure or for repair purposes. They are located against an insulated bulkhead through which the evaporator and evaporator fan project into a plenum chamber. A new or reconditioned unit can thus be installed in a matter of minutes.

The units are powered by 4-cylinder gasoline engines which are entirely automatic in both cooling and heating operations. Heating is accomplished by reversing the refrigeration cycle or, by what is popularly called, the "heat-pump" principle.

The insulated body of the car is completely jacketed, and the course of the air circulated through the jacket is from floor to ceiling. Should a portion of the circulating air be required to pass through the loaded portion to take up heat of respiration from fruit or vegetables, then grills in the walls at the floor and in the ceiling can be provided to permit the desired amount of air to pass through the load. Thus the car can be used for the shipment of any perishable commodity that requires a constant temperature, within the range of the thermostats -10 to $60°$ F (-23.3 to $15.6°$ C), and the shipment can be carried through any weather conditions with only the manual adjustments made at the beginning of the trip. Fuel sufficient for 10 days of normal operation is provided and oil reservoirs with capacities of 5 gallons obviate the changing of lubricating oil, except at the end of a trip.

A mean temperature of $-2°$ F ($-18.9°$ C) was maintained in the experimental car as 2 carloads of frozen fish were carried across the Dominion in June and July of 1949. One carload of apples was also shipped in January, and no difficulty was experienced in maintaining a mean temperature of $33°$ F ($0.6°$ C).

The results of the Canadian experiments indicate that the system employed is quite capable of supplying the temperatures required for the shipment of fresh fish, fruit and vegetables, and frozen fish and other commodities under any weather conditions encountered in Canada. However, further tests will be necessary to supply data for studies of its economic feasibility.

Packing Fresh Fish for Shipment

Fresh (unfrozen) fish, as has been indicated already, are shipped in express refrigerator cars in both carload and less than carload lots. In the carload lots the

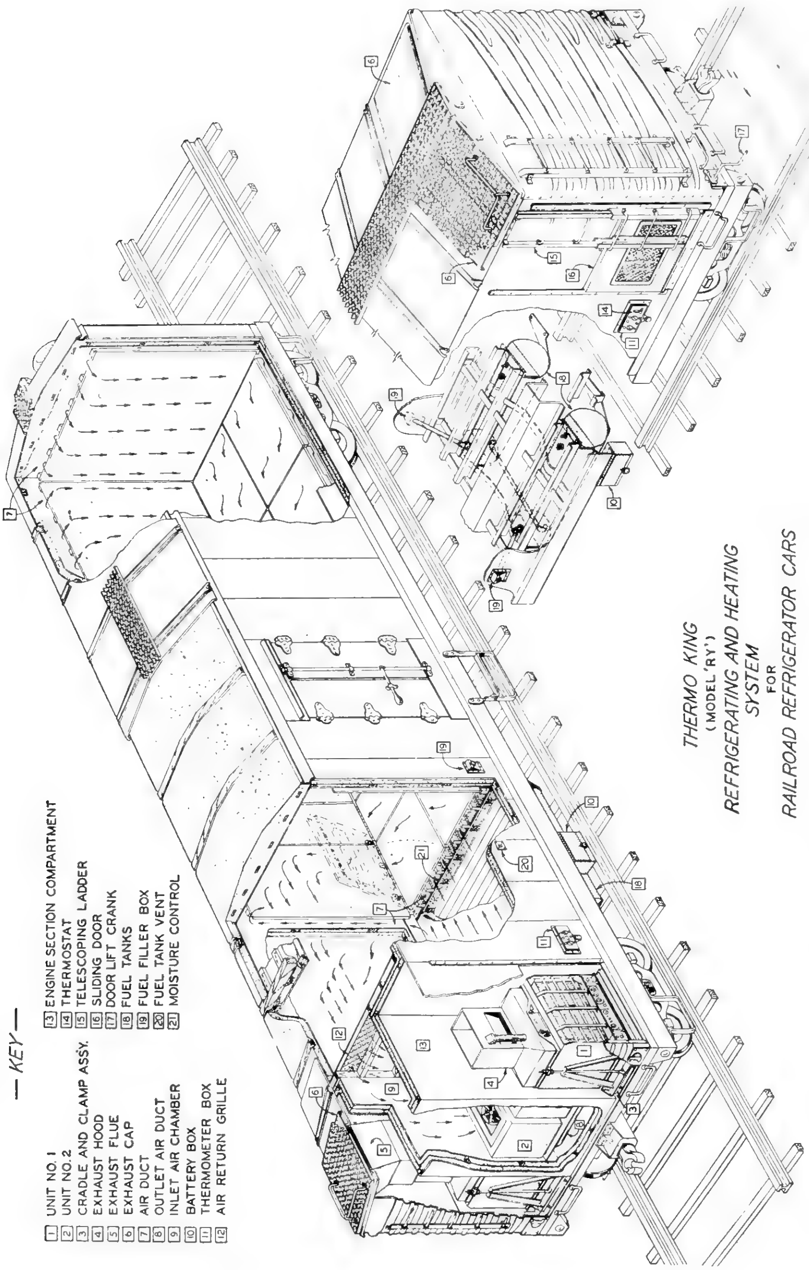
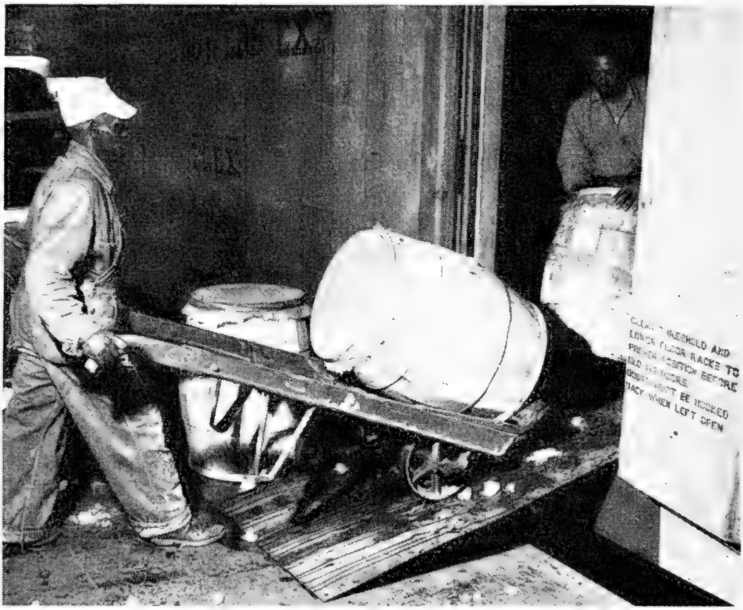


Figure 15–1. A railway refrigerator car being developed by the Canadian National Railroad in cooperation with the Pacific station of the Canadian Biological Board. This car is designed to hold a constant temperature whether the outside air is above or below freezing.

fish are packed 100, 150, or 200 pounds to a box, while in less than carload lots boxes containing 75 pounds or less may be used as well.

In all cases the dressed fish are well "bedded" in finely divided ice, with care being taken to separate the fish from the box by a thick layer of ice. To gain this end the bottom of each packing box is first covered with several shovelfuls of



(Courtesy U. S. Fish and Wildlife Service)

Fig. 15–2. Many seafood products are loaded into refrigerator cars for shipment to the market. Oysters are packed in gallon cans, placed in barrels, and then covered with ice and shipped in refrigerator cars.

fine ice, then layers of fish and ice are added until the box has the required weight of fish. The final or top layer must be ice, of course.

Different techniques are used for different kinds of fish. For example, halibut are packed on their sides, while salmon are packed on their backs. In each case the "pokes" (visceral cavities) are partly filled with ice, and the fish are arranged so that the melt from the ice will drain away rather than accumulate in the "pokes." Practice has shown that the average shipment requires about half as much space for ice as is taken up by the fish. That is to say, a box of fish, just after packing, will consist of $\frac{2}{3}$ fish and $\frac{1}{3}$ ice, by volume. If properly packed the major portion of the ice will be between the fish and the box, and mostly at the top, since under ordinary circumstances the warmest conditions outside the box will be at the top. Since fresh fish usually are fairly well chilled before they are packed in the shipping boxes, only a small proportion of the packing ice is required to take up their sensible (specific) heat; therefore, the major portion is placed where it will afford the best protection against external heat sources.

The carrier (railway company) appears to assume the responsibility of protecting all shipments of fresh fish during the transportation episode. However, in

the case of carload lots the shipper usually supplies the ice for the precooling and initial reicing of the car before it leaves his plant. Salt is rarely, if ever, used in precooling or reicing fresh-fish cars.

In the case of less than carload lots the boxes of fresh fish are sometimes covered with fine ice after being placed in the express refrigerator car. This is done to reduce the melting of the ice in the boxes, especially in hot weather and when the car is to be opened rather frequently.

For packing the fish, however, it is claimed (Bulletin Fifteen, Flak Ice Corporation of New York) that "Flak Ice" has some advantage over crushed ice: it lasts longer than crushed block ice; effects lower temperatures more quickly and maintains them; handles more easily; is not injurious to the surface of the fish because of its flat shape; presents greater contact surface to the fish since it has no sharp projections; and has a greater heat-absorbing capacity for a given volume.

This last claim is made on the assumption that the "Flak Ice" will be colder (will have given up some specific heat as well as latent heat) because there is no need for crushing; whereas the crushed ice may be wet and will, therefore, have gained some of its latent heat. It would not be valid if both forms of ice were at the same temperature when tested, unless the "Flak Ice" were more dense. This is quite possible in view of the wide variation found in the density of crushed ice. Variations between 26 and 42 pounds per cubic foot are said to have been found with crushed ice, depending upon particle size; whereas "Flak Ice" is said to have a density not varying greatly from a mean of 32.5 pounds per cubic foot. It would seem that a more reasonable comparison of cooling capacities could be made on a poundage basis.

Apart from any advantages that might arise from calorific capacities, the flake type of ice does seem to have advantages for the icing of fresh fish. At any rate "Flak Ice" and two modified forms of the same type, called "Pak Ice" and "Belt Ice," are gaining favor in the fishing industry.

"Pak Ice" is made in the form of fine crystals, resembling coarse snow, and is, therefore, soft and easy to handle. A full description of the method of production, applications in industry, and modifications in forms suitable for storage will be found in articles about the "Pak Ice Machine" (Anon., 1939, and Taylor, 1931).

"Belt Ice" is almost identical with "Flak Ice," but the machines which produce it make use of metal belts in a manner slightly different from the system employed in the "Flak Ice" machine. The product has all the characteristics of "Flak Ice."

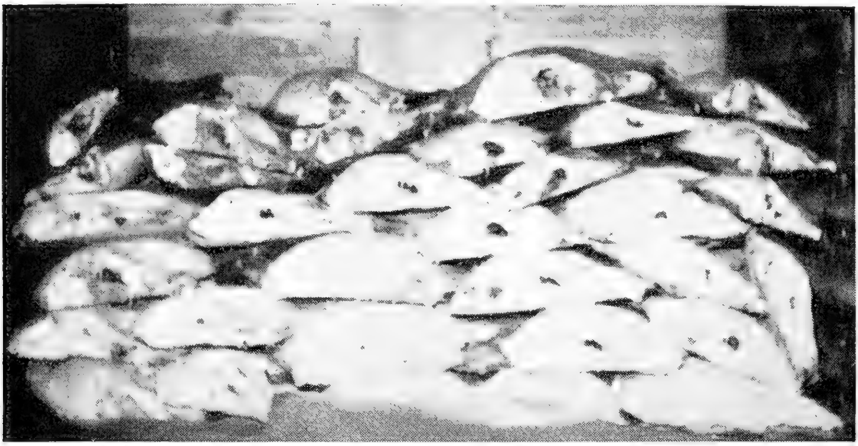
Although there are no standard dimensions for the various sizes of wooden boxes used for fresh fish, the dimensions used by several fishing companies on the Canadian Pacific Coast are given in Table 83.

TABLE 83. SOME RELATIONS BETWEEN WEIGHT OF FRESH FISH AND SIZE OF SHIPPING BOX ARBITRARILY USED.

Nominal weight of fish (lbs.)	Space required for fish (cu. ft.)	Additional space for ice (cu. ft.)	Volume of box recommended (cu. ft.)	Outside dimensions of box used by several fishing companies in Canada (inches)
75	1.5	0.75	2.25	30½ × 15 × 10
100	2.0	1.0	3.0	34 × 19 × 10
150	3.0	1.5	4.5	40 × 19 × 12
200	4.0	2.0	6.0	42 × 20 × 15

Packing Frozen Fish for Shipment

Frozen round and dressed fish that have been held in storage for some considerable time require a degree of reconditioning before they are shipped. The amount of reconditioning will depend upon the storage conditions and the length of time the fish have been stored. Usually it consists of trimming off discolored spots due to "rusting" and desiccation, melting off the old glaze and accumulated



(Courtesy Otto C. Young)

FIG. 15–3. Frozen halibut and salmon are stacked in refrigerator cars for shipment to the distant markets. The ice bunkers of the cars are loaded with a freezing mixture of ice and salt to keep the temperatures below freezing.

spray, lowering the temperature of the fish and reglazing. The reconditioned fish, except for the larger specimens, are then packed in wooden boxes which are first lined with heavy paper. Apart from the glaze, no ice is used in the packing of frozen fish, for it could serve no useful purpose since the melting point of frozen fish is below that of ice.

Since the storage life of frozen fish depends upon the storage temperature, it is very important that their temperature be kept as low as possible at all times. For this purpose the more modern cold storage plants are equipped with a "shipping room" which is conveniently situated near a railway track or spur and in which the temperature is held well below zero. The reconditioned fish are stored in this room for a sufficient time to depress their temperature well below zero before they are loaded into the car.

As with express refrigerator cars freight refrigerators in which frozen fish are usually shipped are also precooled before loading. The bunker types of refrigerators, employing ice and salt, require at least 20 hours for this purpose. This is the responsibility of the shipper; he determines the proportions of salt to be used, not only in the precooling, but in the subsequent reicing also.

A carload of frozen fish will normally consist of more than one kind and size of fish because a broker will want to satisfy every customer. Most of the fish will be shipped 150 and 200 pounds to a box, a smaller proportion 300 pounds to a box, and only a few 400 pounds to a box. Large specimens of fish, such as

60-pound halibut, are usually shipped unboxed. The boxes are stacked as high as physically possible in the car, with the determining factor being the inside dimensions of the refrigerators. The fish-carrying capacity of a refrigerator car is limited by its size, rather than by the weight of the fish. The size of boxes commonly used for some Canadian Pacific Coast species of fish are given in Table 84.

TABLE 84. SIZES OF WOODEN BOXES FOR FROZEN FISH.

Weight of fish (lbs.)	Kind of fish	Outside dimensions of box used by several fishing companies in Canada (inches)
150	Salmon or "chicken" halibut	42 × 20 × 14½
200	Salmon	42 × 22 × 15½
200	Halibut, 10–20 lbs.	45 × 23 × 14
300	Halibut, 20–40 lbs.	51¼ × 26¼ × 17¼
400	Halibut, large	55¼ × 26¼ × 18¼

In the case of carload lot shipments of frozen fish the shipper stipulates on the shipping bill the frequency of reicing, the amount of ice to be used, and the proportion of salt to be added. As the importance of lower temperatures for transport is becoming recognized, more and more shippers are requesting "Maximum refrigeration," which implies ice and salt in eutectic proportions and the filling to capacity of the bunkers at the designated stations or intervals. Reicing instructions vary with the type of car employed. For example, a shipper using an end-bunker car may request reicing to capacity to be regularly carried out with chunk ice and 30 per cent salt at all icing stations; whereas the same shipper, using an overhead-tank car, may not wish reicing unless the top temperature rises above 10° F (− 12.2° C) and 2400 pounds of ice and 30 per cent salt are used. Since the cooling in the overhead-tank car is not as dependent upon the amount of ice in the bunkers as is that in the end-bunker car, there is no need to keep the bunkers full of the cooling mixture.

However, all shippers of frozen fish do not demand 30 per cent salt in their reicing instructions. Concentrations requested vary from 12 per cent to 30 per cent depending upon the outside temperature and the type of car used. The demand for the higher concentrations seems to be increasing however.

It is also important to note that the method of determining the quantity of salt to be added to a given amount of ice in a bunker is not on a true percentage basis. "30 per cent salt" in railway terminology means 30 pounds of salt to 100 pounds of ice, which is approximately 23 per cent salt in the resultant mixture. The relationship between railway methods of determining the salt concentration in a given mixture and the true concentration, together with the approximate temperatures that might be expected in the resultant mixtures, as given in the International Critical Tables, have been set down in Table 85 (p. 322).

Railroad Containers

Special containers are sometimes used for the transport of perishables on railway cars, trucks, and ships for relatively short trips (a week or less). Usually

TABLE 85. RELATION BETWEEN SALT CONTENT AND POSSIBLE TEMPERATURE FOR SALT AND ICE MIXTURES.

Salt content, true per cent by weight	Ratio salt to ice	Freezing point degrees (F)	(C)	Salinometer reading of brine at 60° F (15.6° C)
5	5.3	27.5	–2.8	18.8
10	11.1	20.4	–6.4	37.2
15	17.6	12.5	–10.8	56.8
20	25.0	2.6	–16.4	75.2
23.3	30.4	–6.0	–21.1	87.6

these are refrigerated by eutectic inserts or "Dry Ice." The containers are insulated and are precooled before the perishables are loaded and the inserts added (Anon., 1943).

Trucks and Trailers

Trucks and trailers are becoming more and more important in the transport of fresh and frozen foods, particularly in the shipment of such perishables as fish. This is due to the great advances that have been made in the refrigerating equipment used in trucks and trailers, which result in temperatures being held closer to those recommended than are held by railway equipment. The improvements in design and refrigerating equipment have added tremendously to the range of the truck so that, whereas 3 years ago a truck would make a 300-mile trip, it is now making a 1,000-mile trip, and the damages to cargo are certainly no greater. For long hauls the railway refrigerator car is still the most important vehicle; but, if freight rates continue to increase, the truck and trailer will become serious competitors, even for long hauls. It is probable that even though truck rates are somewhat higher than rail freight rates, trucks will continue to gain favor because of their greater flexibility, better service, and better holding conditions. Unless railway companies improve their facilities, trucks and trailers may take over the major portion of the carriage of perishable traffic.

Unlike railway cars, which are usually of standard dimensions and construction, the refrigerated trucks are made directly to suit the needs of the owner, not only in size, but in insulation and refrigeration equipment also. That is, some are designed for short hauls with moderate insulation, while others are built for long hauls involving both cooling and heating equipment.

The development of refrigeration equipment for trucks and trailers seems to be well in advance of that for railway cars, for there are thousands of trucks in the United States equipped with mechanical or other types of refrigeration facilities in operation now.

The types of refrigeration equipment most favored are the "Dry Ice," the hold-over plates, and the mechanical types. Since each type has a special application for which it is best suited, it is likely that all three will continue to expand. The "Dry Ice" systems have been described under the previous sections in railway refrigerator cars.

Hold-Over Plate System. The hold-over plate system is one that is favored for short hauls or for local deliveries, where trucks can be serviced nightly at the

parent or other refrigeration plant. The system gets its name from the fact that a eutectic solution is generally used in plates to maintain the desired temperature within the insulated van while the refrigerating machinery is not in operation. The eutectic plates may be frozen either by the parent plant equipment or by a compressor driven by the truck motor or by an auxiliary motor forming part of the equipment. The auxiliary motor may be an electric motor which must be plugged in to some convenient electrical outlet while the truck is standing still (overnight), or it may be a gasoline engine separate from or in addition to the electric motor. The hold-over period is a function of the amount of eutectic used in relation to the usual factors entering into heat balance calculations. Similarly, the temperature that will be obtained in the truck will depend upon those factors; as it is not ordinarily controlled, outside conditions cause it to fluctuate somewhat. The hold-over system is simple and relatively inexpensive, but has the disadvantage of being inflexible with regard to holding temperature.

Mechanical Systems. The mechanical systems that appear to be gaining favor with truck and trailer operators are the packaged types already outlined under railway transport sections. Mechanical units first used on trucks were mounted under the trucks where air circulation was assured and radiation effects minimized. This advantage was outweighed by the disadvantages of water and dirt hazards, so that now mechanical units are mounted in the front of the van. In trucks the units are mounted over the cabs and in trailers they are similarly mounted or occupy a section on the floor across the front of the van.

The Transport of Fish by Air

The transport of fishery products by air is not of great commercial significance and is not likely to become so for some time. Numerous parcels of fishery products of a specialty nature, such as live lobsters, have been and are being carried by air, but they do not constitute an important portion of the total volume shipped and are therefore regarded as experiments.

It is probably needless to observe that cost is the main inhibiting factor to great expansion of air cargo traffic; therefore, air-borne fish cannot compete on a price basis with that hauled by surface carriers. However, the great reduction in elapsed time between catch and consumption of some fishery products can raise these products into a superior or luxury class on a quality basis, and thus premium prices can be assessed to take care of the extra transportation costs. The volume of such traffic will of course depend upon the number of individuals willing to pay premium prices for air-borne fish of assured quality. Although experiments and surveys are under way in the United States and Canada to determine the relation between premium prices (excess over ordinary market prices) and demand in various income groups in some representative cities, these studies have not progressed to the point where definite conclusions can be drawn.

As far as is known the airplanes used in these experiments have no special equipment for maintaining the required conditions for the carrying of fishery products. The responsibility for protection seems to be assumed by the shipper. Protection is afforded by the container, which is usually of the standard "Insulpak" variety consisting of an inner and an outer carton separated by insulating pads. Chilled and wrapped fillets are placed in these cartons which are then kept at

32° F (0° C) until delivery to the airport. The characteristics of the cartons are such that the temperature inside rises approximately at the rate of 3° F (1.7° C) in 4 hours with an outside temperature of 70° F (21.1° C).

FIG. 15–4. Many shipments of live lobsters are made by airfreight. The lobsters are packed in specially constructed, waterproof, corrugated fiberboard cartons, and covered with wet seaweed. In extremely warm weather a tray of water ice is added to keep the lobsters cool. The cartons shown above contain 50 lbs. of lobsters and have a gross weight of 70 to 75 lbs. when packed. Other sizes of cartons are available.

(*Courtesy American Airlines, Inc.*)

Factors Affecting the Rate of Ice Melting

In view of the wide application of ordinary ice in the preservation of fishery products before, during, and after the transportation episodes it might be profitable to review the factors that are held to affect the rate of ice melting and bring to the reader a few observations covering these factors. For ease of discussion and clarity the factors will be considered under separate sections as follows:

Temperature of the Surrounding Air. Since the melting of ice is a purely physical change involving an exchange of heat between surrounding media (fish, air, etc.) and the ice, the rate of melting will vary directly with temperature difference between the ice and the surrounding media, all other factors being equal. This is known from elementary physics, and for most practical calculation the qualification "all other factors being equal" can be ignored. More precise calculations, however, must take account of these other factors.

Size of Ice Particles. Considering again the change in phase as caused by an exchange of heat, we may observe that for a given temperature difference between surrounding media and ice the rate of melting will depend upon the exposed area of the ice, or, in other words, upon the size of the ice particles, with the qualification that all other factors be kept the same. This, also, is elementary, and was a reason that used to be given by some fishermen when they demanded

coarse ice to ice down their fish. The fact was overlooked that in attempts to conserve ice the primary purpose to preserve the catch was being jeopardized. Obviously, the finer the ice the better the preservation of fishery products.

Velocity of the Surrounding Air. Intuitively it will be gathered that the rate of ice melting will depend a great deal on the velocity of the air passing over the exposed surfaces of the ice. The higher the velocity the greater the rate of melting. According to a report of work done by Paul W. Scates at the University of Tennessee in 1931, every square foot of exposed ice area may produce an added pound of water for every increase in velocity of the air of 400 feet per minute. That is to say, if other factors remain constant, then an increase in the velocity of the air from 100 to 500 f.p.m. would increase the ice melting by approximately 1 pound for every square foot of ice exposed to the moving air. A practical application of this knowledge dictates that ice and iced fish be protected from moving air.

Humidity. Although it might not be readily appreciated, the relative humidity of the space surrounding ice has a significant effect upon its rate of melting. This is clearly indicated in the report of the Tennessee experiments just referred to, and, as might be expected, the effect is an increase in the melting rate with increase in relative humidity. The explanation is based on the greater amount of water condensed out of the surrounding space, giving up its latent heat of vaporization to the ice and thus increasing the rate of meltage.

"Aged" and "Green" Ice. Although the "age" of ice or its storage life has no effect on its rate of melting, as late as 1938 it was held as an important factor by many fishermen. These fishermen were so serious in their beliefs that they would refuse to use what they termed "green" ice, that is ice that had been freshly made, even though its temperature might be 10 or more degrees blow its melting point. It was necessary to demonstrate, in a practical way, that the length of time ice was kept in storage had no effect on its heat absorbing capacity once temperature equilibrium had been reached. Experiments were performed at the Pacific Fisheries Experimental Station of the Fisheries Research Board of Canada and involved not only determinations of the latent heat of fusion of ordinary ice stored for different periods, but included actual melting rates and temperatures attained under similar conditions for the different ices (Young, 1938).

Although it is not known how the idea was conceived that storage period had any effect on the thermal properties of ice, it could have arisen from the observation by fishermen that ice that came out of storage appeared to have greater heat-absorbing capacities than that of ice just out of the freezing tank; this was attributed to the storage rather than the lower mean temperature. Simple calculations show that the heat-absorbing capacity of ice is increased 1 per cent for about every 3 degrees lowering in temperature below its freezing point; therefore, the storing of ice has the effect of permitting the ice to reach equilibrium with its surroundings. For practical purposes this requires hours rather than days or weeks. The practice of storing ice at 20° F (− 6.7° C) or lower seems to be gaining favor, and this lowering of temperature about 12° F (6.7° C) below the freezing point increases its heat-absorbing capacity about 4 per cent.

REFERENCES

Albert, G. D., "Some Essentials of Truck Trailer Refrigeration," *Western Canner and Packer,* 39, No. 13, 86 (1947).

Albert, G. D., "Truck Trailer Refrigeration for Frozen Foods," *Quick Frozen Foods,* **11,** No. 8, 98–100, 142, 174 (1949).

Anon., "Vilter Announces New ½-ton Capacity Pak Ice Machine," *Refrig. Eng.,* **37,** 58 (1939).

Anon., Bulletin Fifteen, Flak Ice Corporation, 360 Furman Street, New York, N. Y.

Anon., "The Transalt Plan," *Modern Refrigeration,* **46,** 255–256 (1943).

Anon., "Ice Frozen on Steel Belt in New Machine Made in Northwest," *Ice and Refrig.,* **109,** No. 6, 69 (1945).

Anon., "Transportation of Fishery Products," *Fishing Gazette,* **62,** No. 12 (Ann. Rev.), 228–234 (1945).

Anon., "Cleaning. Useful Techniques for Refrigerator Cars," *National Provisioner,* **115,** No. 21, 18–19 (1946).

Anon., "Fresh Frozen Shrimp Over Desert Roads," *Food Industries,* **18,** No. 10, 107–108 (1946).

Anon., American Assoc. of Railroads Report for 1947.

Anon., "'Dry-Ice' Car Tested," *Quick Frozen Foods,* **9,** No. 11, 79–80 (1947).

Anon., "Mechanical Refrigerator Car Announced," Tests Conducted by U. S. Dept. of Agriculture, *Ice and Refrigeration,* **113,** No. 1, 21–23, 72 (1947).

Anon., "New 'Dry-Ice' Freezer Railroad Car," *Food Freezing,* **2,** No. 7, 484 (1947).

Anon., "Transportation Developments. Split-Absorption System Refrigerated Car," *Quick Frozen Foods,* **9,** No. 11, 78–80 (1947); *Food Industries,* **19,** No. 7, 80–82 (1947).

Anon., "Portable Reefers for Water Transportation," *Quick Frozen Foods,* **11,** No. 2, 78–82 (1947).

Anon., "Truck Transportation Soars for Frozen-Food Cargoes," *Quick Frozen Foods,* **11,** No. 6, 41 (1949).

Anon., "Report on Experimentation and Development in Connection with Air Cargo Traffic in Fishery Products," *T. C. A. Marketing Service Bulletin,* No. 13.

Beatty, S. A., "Icing of Refrigerator Cars," Fisheries Research Board Canada, *Prog. Repts., Atlantic Stations,* **43,** 13–14 (1948).

Biehl, A. M., "Refrigeration Systems for Mobile Vehicles," U. S. Pat. 2,374,972 (1945).

Cook, W. H., "Refrigerated Transport," *Food in Canada,* **6,** No. 10, 29 (1946).

Field, C., and Adams, A., "Eutectic Salt Ice," *Refrig. Eng.,* **31,** 95–108 (1936).

Hicks, E. W., "Rail Transport of Perishable Foods," Council of Scientific and Industrial Research. (Australia) Division of Food Preservation and Transport, *Research Rept.,* No. 6 (1948).

Johnson, E. F., "Air Cargo Problems," *The Carrier's Viewpoint,* M. P. **19,** No. 8, 120–124 (1946).

Larsen, S. A., "Air Cargo Research and the Marketing of Fishery Products," *Natl. Fisheries Inst. Yearbook,* **27** (1946).

Larson, J. S., Mixon, J. A., and Stokes, E. C., "Marketing Frozen Foods, Facilities and Methods," U. S. Dept. Agr. Production and Marketing Administration (1949).

Martin, J. W., "Transportation of Quick Frozen Foods," *Quick Frozen Foods,* **2,** No. 1, 15 (1939).

Montgomery, P. H., "Railway Transportation of Perishable Products," *Refrig. Eng.,* **50,** 109–112, 146 (1945).

Plummer, K. V., "The Transportation of Frozen Foods," *Quick Frozen Foods,* **9,** No. 11, 81–82 (1947).

Ramspeck, R., "Flying Fish to Market," *Natl. Fisheries Inst. Yearbook,* **1949,** 61 (1949).

Rohn, A. C., and Clark, J. H., "Refrigeration Equipment for Merchant Ships," *Refrig. Eng.*, **44**, 10–16 (1942).

Scates, P. W., "The Rate of Ice Melting," *Refrig. Eng.*, **22**, 15 (1931).

Schlumbohm, P., "Automotive Refrigeration by the Transitory Cycle," *Refrig. Eng.*, **42**, 14–16 (1941).

Taylor, W. A., "Pak Ice Machine," *Refrig. World*, **66**, No. 11, 12–14 (1931).

Townshend, J. L., "Refrigerator Cars with Ice Overhead," *Refrig. Eng.*, **45**, 243–246 (1943).

Williams, B. E., "Refrigerator Car and Method of Using," U. S. Pat. 2,381,796 (1945).

Willis, A. H., Short, B. E., and Woolrich, W. R., "Ice Melting and Freezing Rates," *Refrig. Eng.*, **39**, 307–310 (1940).

Young, O. C., "A Jacketed Cold Storage Room," *Contributions to Canadian Biology and Fisheries*, **7** (series C Industrial No. 11), 497–504 (1933).

Young, O. C., "The Roof-Tank Refrigerator Car," Fisheries Research Board of Canada, *Prog. Repts., Pacific Coast Stations*, **17**, 13–15 (1933).

Young, O. C., "Ices," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **35**, 18–22 (1938).

Young, O. C., "Refrigerator Car Tests IV," Fisheries Research Board of Canada, *Prog. Repts., Pacific Coast Stations*, **62**, 17 (1945).

Young, O. C., and Taylor, D. H., "Refrigerator Car Experiments. VII. A Road Test with a Mechanical Car Under Heating Conditions," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **78**, 21–24 (1949).

Zarotschenzeff, M. T., "Altek System in Europe," *Ice and Refrig.*, **96**, 285–288 (1939); and *Ibid.*, **96**, 374–378 (1939).

CHAPTER 16

Refrigeration and Freezing of Fish

Importance of Refrigeration

As fish and shellfish are among the most perishable of food products, it is necessary that they be handled in such a way as to retain their "freshness" from the moment of capture to consumption. There are numerous excellent methods of preserving fish, including refrigeration, freezing, canning, salting, drying, smoking, and pickling. However, at temperatures above 32° F (0° C) fish deteriorate so quickly that it is necessary to pack them in crushed ice or otherwise refrigerate them, even though they are to be held for only a short time prior to use or preservation by some other method (e.g., salting or canning). Refrigeration is, therefore, by far the most important and generally used method of preserving fish since it removes them from the class of extreme perishables and permits an extremely variable supply to be stabilized and moved into the market as necessary to meet a highly fluctuating demand. There are few industries which depend more fully on refrigeration than the fish industry.

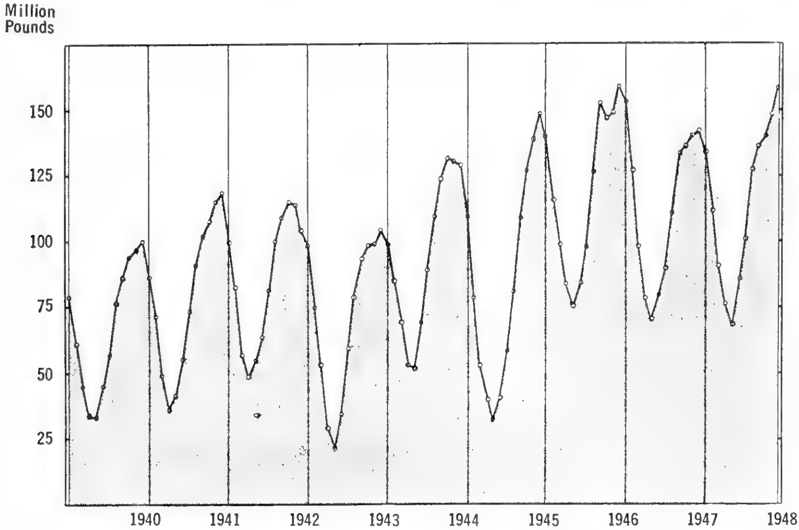
This chapter is devoted solely to the refrigeration and freezing of fish. The methods of refrigeration and freezing of shellfish and other fishery products are presented in the chapters in which the technology of the capture and utilization of these products are considered.

Location and Extent of Industry

The business of freezing and storing fish is of much greater importance in the United States than in any other country in the world. The American industry is located principally in the New England, Pacific coastal, and Middle Atlantic states, and in Alaska and the Great Lakes region. In New England the principal species frozen are rosefish, whiting, cod, haddock, mackerel, pollock, swordfish, flounder, and herring. In the Middle Atlantic states mackerel, whiting, haddock, cod, and flounder are the species frozen in the greatest quantity. In the South Atlantic and Gulf states mullet, grouper, Spanish mackerel, squeteague, and redfish are frozen in considerable quantities. On the Pacific Coast salmon, halibut, tuna, smelt, rockfish, black cod, and flounder are the most important. In Alaska halibut and salmon are the principal species frozen. Chubs, lake herring, ciscoes, and lake trout from the Great Lakes are the fresh-water species frozen in greatest quantity.

Most of the fish are frozen in the late spring, summer, and autumn and held until winter and spring. The maximum holdings are usually in November and the minimum in March or April. However, there is some freezing during every month of the year. The quantities of the various fish frozen in the United States and Alaska in 1949 are indicated in Table 86 (pp. 330–331). In this table the pro-

duction of frozen fishery products by geographical sections is also presented. Cold storage holdings of fish and fishery products are given in Table 87. Most of the frozen fish and fishery products are held in the New England, Middle Atlantic, and Northern Pacific coastal states, and in the Great Lakes region.



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 16–1. During 1948, stocks of frozen fish averaged slightly more than in 1947. In the early part of the year they were somewhat lower than in 1947, but large holdings in the latter part of the year raised the average above the 1947 level. A peak of 158 million pounds was reached on December 1—only slightly lower than the record holdings of November 1, 1946.

Production of frozen fish set a new record of 291,987,979 pounds—an increase of 18 per cent from the previous year. The largest gains recorded among major species were in the production of rosefish fillets, whiting of all kinds, and halibut. Freezings of mackerel registered a sharp decline in 1948. It is estimated that a catch of approximately 625 million pounds of fish and shellfish was required to produce the nearly 292 million pounds of round, dressed, and drawn fish, fish fillets, and packaged shellfish frozen during 1948.

The Nature of the Preservation of Fish by Freezing

Fish are generally recognized as being highly perishable. Shortly after they are caught, certain changes begin to take place, at first not undesirable, but which, if permitted to continue, rapidly destroy the suitability of the fish for human consumption. One of the earliest changes is the coagulation of the cell proteins which causes a general body rigidity or stiffness, known as *rigor mortis*. This condition comes about sooner and lasts a shorter time at higher temperatures than at lower temperatures. *Rigor mortis* is a characteristic of perfectly fresh fish. After it passes away, various other changes occur, some of an external character which serve as an index to the quality of the fish and others of a chemical nature which affect the quality of the flesh. These changes are principally as follows:

Autolysis. The tissues of fish, like those of other animals, contain enzymes which

TABLE 86. PRODUCTION OF FROZEN FISHERY PRODUCTS—BY GEOGRAPHICAL SECTIONS AND SPECIES IN 1949.

Species	New England	Middle Atlantic	South Atlantic	North Central, East	North Central, West	South Central	Pacific	Alaska	Total
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
SALT-WATER FISH									
Bait and animal food	586,411	2,571,007	353,368	—	—	119,418	3,560,539	3,555,524	10,746,267
Bluefish	17.862	398,270	15,004	2,562	—	3,633	—	—	437,331
Butterfish	258,359	626,108	20,156	294	—	—	—	—	904.917
Cod, haddock, hake, and pollock (ex. fillets)	495,478	329,244	6,080	—	—	900	135,862	59,446	1,027,010
Croakers	1,290	132,388	674,980	—	—	19,332	—	—	827,990
Eels	36,905	149,150	15,163	2,985	—	—	—	—	204,203
Fillets:									
Cod	4,022,209	118,711	350	—	—	17,800	238,182	—	4,397,252
Flounder (inc. sole)	3,315,572	60,269	9,267	—	—	—	2,732,128	2,250	6,119,486
Haddock	15,676,219	90,048	—	—	—	—	—	—	15,766,267
Ling cod	—	—	—	—	—	—	377,954	839	378,793
Mackerel	303,507	900	—	—	—	—	107,258	—	411,665
Pollock	4,064,619	2,472	—	—	—	—	—	—	4,067,091
Rosefish (ocean perch)	62,059,531	—	400	—	—	—	—	—	62.059,931
Whiting (inc. split butterfly)	4,621,504	11,602	—	—	—	—	—	—	4,633,106
Other fillets	1,278,456	5,204	31,447	1,770	15,915	6,786	1,992,843	40,835	3,373,256
Flounders (inc. sole, fluke, and Cal. halibut)	410,832	521,438	139,793	537	—	202,305	112,374	—	1,387,279
Halibut	217,789	29,464	—	—	—	500	7,201,206	23,255,980	30,704,939
Herring, sea	1,040,366	1,705,796	—	—	—	—	32,104	90,000	2,868,266
Mackerel (ex. fillets, Spanish, and king)	1,782,599	599.559	400	—	—	—	155,579	—	2,538,137
Mullet	—	141,444	786,407	4,592	—	265,950	—	—	1,198,393
Sablefish (black cod)	—	—	—	—	—	—	1,992,572	3,706,421	5,698,993
Salmon:									
King or chinook	—	—	—	—	—	—	2,483,396	2,037,446	4,520,842
Silver or coho	—	—	—	—	—	—	2,548,118	5,782,528	8,330,646
Fall or chum	—	—	—	—	—	—	785,066	835,230	1,620,296
Pink	—	—	—	—	—	—	51,081	1,933,930	1,985,011
Steelhead trout	—	—	—	—	—	—	52,074	15,286	67,360
Unclassified	100	11,421	—	—	—	—	233,756	1,256,988	1,502,265
Scup (porgies)	124,415	211,320	212,638	—	—	—	—	—	548.373
Sea trout (weakfish, gray and spotted)	—	130,111	506,411	—	—	136,839	—	—	773,361
Shad (inc. roe shad)	1,840	6,953	25,672	—	—	—	63,897	—	98,362
Shad roe	357	19,236	23,894	7,994	345	—	9,149	—	60,975
Smelt	28,538	72,236	—	145,830	—	—	760,773	—	1,007,377
Swordfish	161,956	1,795	—	—	—	—	6,335	—	170.086
Tuna	124,028	11,996	—	—	—	—	1,276,663	—	1,412,687
Whiting (silver hake):									
Round	1,499,416	482,323	—	—	—	3,200	—	—	1,984,939
Headed and gutted (ex. fillets)	34,712,151	14,999	—	—	—	—	—	—	34,727,150
Unclassified salt-water fish	2,183,995	1,820,569	2,479,258	868,125	108,476	1,841,591	4,842,120	1,054,665	15,203,799
Total salt-water fish	139,031,304	10,276,033	5,300,688	1,034,689	124,736	2,618,254	31,751,029	43,627,368	233,764,101
FRESH-WATER FISH									
Bait and animal food	—	—	—	18,802	1,007,000	—	—	—	1,025.802
Blue pike and sauger (ex. fillets)	—	19,392	—	201,373	2,368	—	—	—	223,133
Catfish and bullheads	50,136	1,845	339,035	22,758	60,699	101,545	—	—	576,018
Chubs	43,861	161,293	940	817,221	—	—	—	—	1,023,315

Fillets:									
Blue pike and sauger	—	51,866	—	172,470	510	—	—	—	224,846
Lake herring	169	—	—	37,130	—	—	—	—	37,299
Yellow perch	4,640	—	—	89,748	—	—	—	—	94,388
Yellow pike	—	818	—	15,791	1,774	—	—	—	18,383
Other fillets	—	770	—	5,679	—	—	—	—	6,449
Lake herring and cisco (ex. fillets)	—	37,606	—	1,139,016	232,000	—	—	—	1,408,622
Lake trout	5,962	101,731	—	109,107	42,337	625	—	—	259,762
Pickerel (jacks or yellow jack)	—	46,104	—	82,091	34,500	—	—	—	162,695
Sturgeon and spoonbill cat	—	227,148	14,119	7,681	—	—	—	—	248,948
Suckers	—	—	—	15,638	—	—	—	—	15,638
Tullibee	—	2,160	3,950	—	42,000	—	—	—	48,110
Yellow perch (ex. fillets)	491	2,129	—	119,945	—	—	—	—	122,565
Yellow pike (ex. fillets)	197	128,687	280	55,649	—	1,955	—	—	186,768
Whitefish	16,282	293,910	6,225	102,068	6,217	—	—	—	424,702
Unclassified fresh-water fish	2,051	716,472	36,998	373,658	101,025	107,789	3,147	—	1,341,140
Total fresh-water fish	123,789	1,791,931	401,547	3,385,825	1,530,430	211,914	3,147	—	7,448,583
SHELLFISH									
Clams	45,114	10,696	15,351	—	—	—	267,029	27,723	365,913
Crabs (inc. crab meat)	—	198,840	619,663	36	268	54,731	416,144	116,770	1,406,452
Lobster tails (spiny lobster)	45	58,296	219,661	5,545	3,689	20,969	597,443	—	905,648
Oysters	33,809	400	109,549	—	—	26,496	237,620	—	407,874
Scallops	3,647,684	400,521	147,079	2,340	—	1,000	—	—	4,198,624
Shrimp (inc. shrimp meat)	95,975	1,442,706	3,698,313	12,184	—	25,983,598	1,220,684	—	32,453,460
Squid	2,262,697	1,251,024	64,083	—	—	3,639	547,042	—	4,128,485
Unclassified shellfish	128,027	485,322	39,770	347	400	42,859	41,153	5,000	742,878
Total shellfish	6,213,351	3,847,805	4,913,469	20,452	4,357	26,133,292	3,327,115	149,493	44,609,334
Total fish and shellfish	145,368,444	15,915,769	10,615,704	4,440,966	1,659,523	28,963,460	35,081,291	43,776,861	285,822,018

Note: The sections indicated include the following states:
NEW ENGLAND—Maine, Massachusetts, Rhode Island, and Connecticut.
MIDDLE ATLANTIC—New York, New Jersey, and Pennsylvania.
SOUTH ATLANTIC—Maryland, District of Columbia, Virginia, South Carolina, Georgia, and Florida.
NORTH CENTRAL, EAST—Ohio, Indiana, Illinois, Michigan, and Wisconsin.
NORTH CENTRAL, WEST—Minnesota, Iowa, Missouri, North Dakota, Nebraska, and Kansas.
SOUTH CENTRAL—Kentucky, Tennessee, Alabama, Mississippi, Louisiana, Texas, and Arkansas.
PACIFIC—Washington, Oregon, California, Colorado, Utah, and Montana.
ALASKA

Source: U. S. Fish and Wildlife Service, *Commercial Fisheries Statistics*, **516** (1950).

TABLE 87. 1949 HOLDINGS OF FROZEN FISHERY

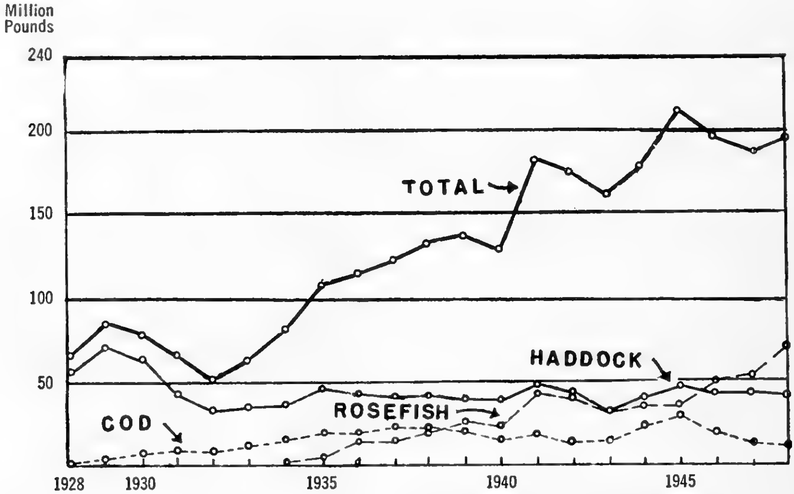
Species	January 1	February 1	March 1	April 1
	Pounds	Pounds	Pounds	Pounds
SALT-WATER FISH				
Bait and animal food	1,817,251	2,085,208	2,126,323	3,976,775
Bluefish	336,925	333,964	187,930	141,380
Butterfish	395,561	288,066	250,521	143,861
Cod, haddock, hake, and pollock (ex. fillets)	1,667,729	1,529,549	1,449,674	1,348,502
Croakers	313,842	174,101	94,533	241,037
Eels	195,242	238,398	181,145	114,273
Fillets:				
Cod	8,635,925	7,607,365	6,349,863	6,777,888
Flounder (inc. sole)	4,698,786	4,081,606	3,129,865	2,368,373
Haddock	7,157,472	5,658,303	5,030,328	4,070,721
Ling cod	131,178	150,437	143,992	121,205
Mackerel	574,156	454,477	448,068	316,137
Pollock	3,972,769	3,999,220	3,380,155	2,528,413
Rosefish (ocean perch)	12,883,234	9,828,418	7,030,772	3,676,962
Whiting (inc. split butterfly)	1,810,558	1,723,927	1,191,963	884,209
Other fillets	1,389,874	1,368,958	1,126,280	819,942
Flounders (inc. sole, fluke, and Cal. halibut)	1,033,672	1,015,765	938,724	1,045,320
Halibut	13,516,355	8,766,243	6,293,082	3,192,124
Herring, sea	1,231,265	1,120,658	825,866	841,820
Mackerel (ex. fillets, Spanish, and king)	4,017,300	3,329,860	2,447,423	1,261,818
Mullet	723,666	744,536	624,539	601,841
Sablefish (black cod)	4,674,840	5,539,581	3,684,309	3,033,990
Salmon:				
King or chinook	4,167,289	3,206,030	2,531,395	1,901,337
Silver or coho	3,743,984	2,738,982	2,206,414	1,432,897
Fall or chum	1,899,568	1,672,105	1,363,252	1,073,055
Pink	159,014	144,021	126,409	118,880
Steelhead trout	73,083	40,656	67,183	91,317
Unclassified	1,479,270	1,246,374	1,288,721	925,099
Scup (porgies)	800,632	697,718	671,462	467,283
Sea trout (weakfish, gray and spotted)	471,711	453,544	378,841	282,194
Shad (inc. roe shad)	229,402	184,564	151,740	93,323
Shad roe	59,118	59,542	47,891	28,481
Smelt	1,430,634	1,353,363	1,956,704	2,215,950
Swordfish	1,690,924	1,896,711	1,807,408	1,554,532
Tuna	906,200	467,117	193,431	345,215
Whiting (silver hake):				
Round	5,164,531	4,189,643	1,862,421	1,058,630
Headed and gutted (ex. fillets)	8,506,880	7,154,236	6,098,855	4,239,150
Unclassified salt-water fish	12,389,989	10,609,213	10,229,354	8,156,273
Total salt-water fish	114,349,829	96,152,459	77,916,836	61,490,207
FRESH-WATER FISH				
Bait and animal food	2,732,795	2,433,171	2,073,906	2,312,205
Blue pike and sauger (ex. fillets)	955,039	689,463	503,600	285,866
Catfish and bullheads	346,343	334,567	347,456	264,881
Chubs	1,028,571	798,003	633,067	402,842
Fillets:				
Blue pike and sauger	502,725	243,458	292,074	380,297
Lake herring	123,342	110,067	131,021	99,019
Yellow perch	229,591	186,614	123,034	115,756
Yellow pike	84,742	75,921	121,190	132,740
Other fillets	119,657	96,352	91,458	91,810
Lake herring and cisco (ex. fillets)	1,806,814	1,067,190	965,650	656,514
Lake trout	532,310	452,938	415,258	344,013
Pickerel (jacks or yellow jack)	146,929	317,559	108,383	93,011
Sturgeon and spoonbill cat	490,230	420,066	383,904	313,210
Suckers	20,694	15,624	12,534	19,999
Tullibee	218,148	182,111	167,419	42,444
Yellow perch (ex. fillets)	608,759	535,625	400,088	326,270
Yellow pike (ex. fillets)	191,387	196,811	211,198	260,867
Whitefish	1,677,397	1,372,222	1,346,241	1,091,691
Unclassified fresh-water fish	1,096,012	1,244,066	1,012,930	735,751
Total fresh-water fish	12,911,485	10,771,828	9,340,411	7,969,186
SHELLFISH				
Clams	330,461	243,549	165,088	142,764
Crabs (inc. crab meat)	563,350	472,685	455,405	337,740
Lobster tails (spiny lobster)	780,738	723,746	613,816	754,923
Oysters	270,299	246,142	231,590	293,976
Scallops	3,098,578	2,843,008	2,410,115	1,465,123
Shrimp (inc. shrimp meat)	16,725,598	14,416,871	11,464,434	8,890,841
Squid	1,149,703	898,174	768,995	652,059
Unclassified shellfish	793,485	866,993	771,759	725,565
Total shellfish	23,712,212	20,711,168	16,881,202	13,262,991
Total fish and shellfish	150,973,526	127,635,455	104,138,449	82,722,384

Source: U. S. Fish and Wildlife Service, *Commercial Fisheries Statistics*, **516** (1950).

PRODUCTS—BY SPECIES AND MONTHS.

May 1	June 1	July 1	August 1	September 1	October 1	November 1	December 1	December 31
Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
4,977,578	3,490,658	3,567,400	3,466,412	2,895,573	2,436,020	2,067,767	2,089,844	2,140,915
144,050	158,095	146,703	124,568	271,359	311,367	390,261	388,366	370,890
98,498	80,294	74,252	157,839	223,921	415,037	558,008	768,666	752,465
1,099,530	982,760	1,069,200	941,866	903,391	911,526	1,116,151	1,075,082	1,349,381
123,231	106,389	185,246	363,340	738,297	759,762	686,179	432,799	390,075
79,370	115,962	135,441	123,985	112,343	173,715	212,712	253,146	209,561
7,072,158	7,021,438	6,563,496	7,685,418	8,039,267	7,058,124	6,657,698	6,836,302	6,351,265
2,240,068	1,834,697	1,856,476	2,003,926	2,734,728	2,870,195	3,046,912	3,191,762	2,866,105
6,132,812	6,969,741	7,615,363	7,773,241	7,921,560	6,561,990	5,265,924	4,563,437	3,696,058
110,230	159,296	153,681	147,985	159,483	191,558	191,743	72,585	54,530
260,875	240,991	284,571	224,473	221,738	183,806	204,218	213,011	201,196
2,614,537	2,447,431	1,980,177	1,663,177	1,523,177	1,213,368	1,154,962	1,483,582	2,004,817
3,377,656	6,089,603	8,626,015	11,515,766	14,025,581	14,075,356	13,853,533	14,475,792	14,141,844
688,123	596,172	598,378	2,264,961	3,096,199	4,022,166	3,987,135	3,747,649	3,573,433
816,790	1,295,085	1,500,082	1,585,100	1,999,241	2,614,553	2,578,532	2,715,862	2,371,905
714,816	839,850	791,413	863,243	870,813	855,478	1,125,605	1,411,939	1,265,979
1,553,994	12,579,823	22,366,095	25,047,999	22,328,120	19,198,688	16,764,408	13,531,062	10,231,148
1,115,374	1,138,736	1,025,780	934,404	710,591	755,532	961,524	891,268	1,826,231
774,329	659,427	1,160,232	1,398,918	1,121,223	1,168,726	1,064,026	1,979,718	2,110,263
426,275	318,507	245,998	207,885	220,153	361,422	387,538	831,880	1,027,152
2,669,066	2,325,167	2,481,503	3,021,141	4,985,997	5,903,190	6,021,423	5,270,546	5,015,637
1,529,864	1,768,957	2,286,137	3,111,717	4,331,757	5,265,574	5,344,355	4,540,978	3,643,172
924,042	817,693	888,911	2,436,096	5,589,839	5,610,508	5,446,952	4,474,443	3,518,701
1,023,992	844,355	757,540	692,072	984,993	808,544	1,120,079	1,702,018	1,843,921
112,583	10,615	14,141	144,600	1,407,347	125,980	110,090	73,227	69,796
69,221	92,638	79,740	115,561	98,020	99,475	109,523	68,488	46,301
487,345	563,219	890,854	826,097	1,717,384	1,299,649	1,469,993	1,308,530	1,272,200
300,889	382,968	698,706	677,308	639,557	664,667	530,550	439,400	401,749
197,227	236,846	259,763	244,952	282,981	526,012	515,717	620,680	852,559
80,155	156,514	235,195	246,579	214,170	185,189	181,769	169,919	167,767
39,216	76,039	86,987	89,348	72,637	79,135	74,715	63,033	61,237
1,830,198	1,474,208	1,374,348	1,336,716	1,557,558	1,311,797	1,077,576	935,557	755,936
1,025,050	806,907	1,005,629	1,036,182	1,093,140	1,183,885	1,124,180	1,376,865	1,264,215
111,051	44,248	679,961	241,537	1,015,553	2,429,107	2,529,181	1,262,262	113,695
1,247,744	1,221,020	1,108,995	2,477,496	1,320,218	1,866,850	1,727,126	1,626,955	1,476,253
1,862,127	2,633,143	7,766,491	8,717,659	16,359,297	19,947,903	21,961,130	20,403,361	18,271,261
7,913,703	8,974,179	9,138,435	10,024,586	11,339,276	11,490,600	13,638,616	15,285,241	14,565,082
55,843,767	69,553,671	89,699,326	103,934,171	123,126,482	124,936,454	125,257,811	120,575,255	110,274,695
2,270,855	2,152,880	2,058,375	1,865,030	1,539,964	1,042,774	720,320	729,495	1,631,043
303,700	523,376	618,396	564,413	453,931	415,742	481,965	529,616	498,073
258,436	376,049	627,466	659,965	599,473	722,371	710,298	787,933	1,001,348
287,986	246,088	340,887	545,706	665,560	774,178	796,682	638,292	670,599
369,810	156,681	222,693	172,119	77,497	114,829	161,459	376,369	560,899
56,057	76,946	101,871	111,160	43,515	53,156	18,502	25,405	144,880
157,655	134,213	154,813	191,684	294,527	450,158	322,279	302,755	266,367
50,554	51,513	54,113	55,359	50,198	58,154	46,687	81,314	70,662
69,891	116,947	151,692	129,453	186,697	161,477	220,531	190,983	168,729
544,350	550,890	420,427	362,266	330,208	307,273	365,371	906,070	1,358,239
304,827	289,454	317,158	348,956	510,917	617,759	795,080	714,092	646,133
138,847	122,472	140,422	123,690	109,354	108,476	172,795	219,338	127,783
281,002	304,821	356,783	372,431	391,251	422,576	436,128	392,991	294,889
23,924	23,774	25,574	26,574	25,769	25,769	26,974	25,771	19,709
27,802	31,902	17,845	103,569	174,828	176,335	165,757	240,901	226,903
258,932	301,429	331,201	417,650	332,981	325,750	489,505	412,385	437,908
263,920	290,906	281,845	229,291	208,896	195,404	279,686	292,043	273,351
746,970	570,231	571,736	836,522	1,326,899	2,026,242	2,505,486	2,171,871	1,707,413
891,512	1,011,225	1,289,056	1,082,543	869,484	779,912	930,732	1,020,120	913,793
7,307,030	7,331,797	8,082,353	8,198,381	8,191,949	8,778,335	9,646,237	10,057,744	11,018,721
258,815	275,573	187,775	193,284	195,376	211,613	198,872	192,538	189,970
339,526	599,625	594,170	705,846	777,531	807,358	808,632	814,567	803,009
529,007	740,137	937,283	806,000	774,729	1,067,128	951,150	1,289,488	1,676,415
293,659	370,276	353,958	314,123	291,180	352,084	254,816	347,392	305,199
1,312,792	1,342,320	1,474,654	1,763,785	2,133,229	1,811,414	2,198,582	2,312,700	2,315,412
7,444,899	7,250,578	7,809,525	6,794,735	6,474,077	8,742,708	12,258,586	18,770,583	16,469,483
904,467	3,052,871	3,912,188	3,818,788	3,709,501	3,040,621	3,535,161	3,402,932	2,862,986
706,106	936,199	979,797	687,445	669,626	860,015	967,456	955,678	896,642
11,789,271	14,567,579	16,249,350	15,084,006	15,025,249	16,892,941	21,173,255	28,085,878	25,519,116
74,940,068	91,453,047	114,031,029	127,216,558	146,343,680	150,607,730	156,077,303	158,718,877	146,812,532

digest the tissues, causing a softening or partial liquefaction and changes of flavor and odor. These changes in red meats are collectively called ripening, and are desirable because they make the meat tender, juicy, and of good flavor. In fish, however, the results are highly disagreeable to the human palate, and ripening or autolysis must be prevented or retarded. A fish whose tissues have been



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 16–2. The production of fresh and frozen packaged fish (fillets, steaks, and split butterfly) in continental United States during 1948 totaled 193,498,001 pounds, valued at $48,819,726 to the processor. These data do not include the production of pan-dressed fish, which in 1947 amounted to 24,906,328 pounds, valued at $2,146,794. When compared with similar data for 1947 (excluding pan-dressed fish), the 1948 production increased 21 per cent in volume and 15 per cent in value.

The most important species in both quality and value, were rosefish and haddock. Fillets accounted for 95 per cent of the total; steaks, 3 per cent; and split (butterflied), 2 per cent.

partially autolyzed is soft and flabby. Packing fish in ice retards, but does not arrest autolysis. As long as a fish is kept frozen hard, autolysis is all but arrested, but when the fish is defrosted autolysis again sets in.

Bacterial Invasion and Putrefaction. The principal fields of infection are the gills, slime of skin, and intestinal tract. The invasion by bacteria begins at once if the fish are kept at warm temperatures, and proceeds somewhat more slowly at ice temperature. First the epithelium of the intestines and the intestinal walls are decomposed; the skin and gills are invaded and acquire a sour or putrid odor.

It is mainly to arrest or retard autolysis and bacterial invasion and putrefaction that low temperatures are employed. Fish packed in ice are still edible after many hours or even several days; but they are in prime condition for only a few hours and are unfit for food, though perhaps not dangerous, after from 1 to 3 weeks. Fitness or unfitness for food is, of course, a matter of opinion. If more than the briefest storage is necessary, the fish must be frozen hard and kept in

that condition for the entire period of storage. Freezing and storage, if done by the best known methods make possible the holding of fish in good edible condition for a year or more.

In the freezing, storing, and defrosting of fish, which are intended to prevent autolysis and putrefaction, certain other undesirable changes may supervene which must be clearly recognized and avoided as far as possible. These are, chiefly:

Internal Crystallization of Water. A fish contains from 65 to 80 per cent water, varying with the amount of fat present. If a small piece of fish is frozen with extreme rapidity, as by immersion in cold mercury or liquid carbon dioxide, and examined microscopically, no physical change is observed. But if frozen slowly, as in an ordinary fish freezer, it will be found that much of the contained water has escaped from the cells and muscle fibres and frozen as ice crystals. This phenomenon is accompanied by a rupturing of cell structures, rapid autolysis, and loss of juices on defrosting; the practical result is that fish frozen slowly are not capable of being held long on being defrosted, but must be consumed without delay.

Desiccation. During the periods of freezing and cold storage the rooms or chambers in which the fish are kept are refrigerated by means of a refrigerant, ammonia or brine, circulating in pipes. These pipes are usually the coldest objects in the rooms, and consequently their surfaces have the lowest water-vapor pressure. Since the fish in the freezer or storage are usually warmer than the pipes, they are of higher vapor pressure. The fish thus lose water by sublimation and the pipes accumulate water as snowy crystals. The fish, unless carefully protected, may in this way rapidly lose 50 or 60 per cent of their weight in a few months. As the fish dries, the skin shrinks and loses its lustre, the tissues become like cork, and the fish is not acceptable as food.

Loss of Flavor. Fish that are quickly frozen, heavily glazed, and stored under the best conditions keep for months with first-rate edible qualities. Yet when storage is unduly prolonged, they become insipid, though still wholesome. The chemical reason for the loss of flavor is not known, though it is generally supposed to be caused by the evaporation of volatile constituents. In addition to loss of flavor there is a development, in fat fish, of a rancid flavor due to changes in the fats.

Rusting. Unless precautions are taken in storage, the fatter fish become "rusty." By this term is meant an exuding of fat to the surface, followed by oxidation and possibly polymerization and other changes. When this condition occurs, the fish has a yellowish or rusty appearance, especially around the vent and belly and on cut surfaces; it is rancid in flavor and probably indigestible. Fat fish, like salmon, mackerel, and lake trout, rust within 2 or 3 months unless proper preventive measures are taken. The exact nature of the changes which constitute rusting is not understood. Some writers think that shrinkage in the fish during freezing forces the fat out in droplets, and the freezing temperatures should be lower than the freezing point of the oil.

Incidental Changes. Other undesirable things may happen more or less incidentally to frozen fish. Snouts, fins, and tails may become broken or scarred; eyes may become glassy; the red corpuscles may be hemolyzed with a diffusion of hemoglobin into the surrounding tissue; and the gall bladder may be broken.

If frozen in cakes or blocks, the fish are pressed out of shape and individual fish cannot be separated from the cake without damage to the skin. If the fish are frozen in brine, some salt may penetrate the tissues and the blood may be discolored by the action of the salt.

Layout, Construction, and Mechanical Equipment of Fish-Freezing Plants

Fish-freezing plants, like almost any other class of plants for commercial operations, have equipment which varies from the simple, crude, and inexpensive to the large, complex, and costly. Most of them are on or near the water; many are not exclusively fish freezers, but take other perishables for cold storage. Most of them make ice, whereas some do a public fish-warehousing business and others are entirely private. The public houses freeze and store fish for customers at a fixed charge and the private houses own the holdings outright, buying fish in the producing season and selling in the consuming season. Practices in freezing and storing fish are not at all standardized as more or less natural, but nevertheless great, differences appear in different regions and with different species of fish.

Construction and Location of Freezers. Many freezers are built on piers so as to be readily accessible by boats, which receive crushed ice through chutes while unloading fish. The better types of freezers are constructed of steel and concrete, with an envelope of corkboard for insulation. Many are of frame construction, with sawdust, felt, or other cheaper material for insulating purposes. Usually the machinery, because of its weight and vibration, is located on the ground floor or in the basement. The receiving, washing, and panning rooms are usually on the ground floor, but are sometimes on the top floor. The sharp freezers are usually on the first or second floor if the fish are received on the first floor, but in one large freezer in New York the fish are received on the ground floor and are washed, panned, and sent to the top floor by continuous chain elevator. In a plant in Portland, Maine the fish are received on the top floor and conveyed through hatches to the sharp freezers on the floor immediately below. More commonly, however, the sharp freezers are on the first or second floor.

The sharp freezers are usually small rooms, having a capacity of from 15,000 to 40,000 pounds, though in some plants larger rooms are more satisfactory. The smaller rooms are usually much longer than they are wide, and are equipped with shelving made of steel pipe through which the brine or ammonia circulates. On these pipes the fish are placed to freeze. The large rooms, especially where brine is circulated, permit loading without excessive elevation of temperature, and consequently with quicker freezing, while the small rooms permit loading without interference with the progress of freezing of lots in other rooms.

The glazing room is usually conveniently located at some point on the route from sharp freezer to storage. When there is no definite room for this purpose, a corridor is often used; sometimes movable glazing tanks are employed in the storage rooms. More often, however, a glazing tank is permanently built in at a convenient place.

The storage rooms are usually large—much larger than the sharp freezers. The refrigerating pipe coils are arranged on the side walls and ceilings. Slatwork is sometimes laid 4 to 6 inches from the floors and side walls to permit circulation of air.

Thermometers should be placed in all cold rooms at places where they are sure

to indicate the true temperature of the rooms and where they may be easily read. The rooms are electrically lighted, and some have pilot lights outside to indicate when the lights are on inside. Concrete walls are usually not covered, but wooden walls are whitewashed or painted.

Mechanical Refrigeration. In nearly all large commercial plants for freezing fish ammonia refrigeration machines are used, and the great majority of these are of the compression type.

A number of relatively small fish freezers and cold storages now have machines which use "Freon-12" as the refrigerant. This refrigerant, or some other refrigerant of the "Freon" group, should be used on freezers placed on board ship since ammonia and other poisonous refrigerants are dangerous when used at sea.

Absorption machines are used to some extent with excellent results; they easily maintain very low temperatures, though are usually not as economical to operate as the compression machines. If absorption machines are used, brine is circulated; if compression machines are used, either brine may be circulated or liquefied ammonia delivered directly to the coils in the rooms for evaporation. This is known as the "direct expansion" system. In some cases where steam is used to drive compression machines there is an amount of exhaust steam coming off at low pressure which is used to operate an absorption machine, brine being circulated through the rooms. Some very large fish freezers are refrigerated by this combination.

Electricity is being used more and more as a prime mover in fish-freezing plants; it is less complicated, requires little attention, and, where nonpeak-load contracts are made with the power companies, compares favorably in expense with the steam-driven plants.

When "direct expansion" is used for chilling the rooms, the liquid ammonia is sometimes fed in through expansion valves at the top of the coils, the temperature being regulated by the expansion valve. The so-called "flooded system" makes use of much larger quantities of ammonia to fill the banks of coils to a high level by expansion valves at the bottom. In this way advantage is taken of the much better heat conductivity of liquid than gaseous ammonia in contact with the pipes. Many plants which operate without flooding the coils often entirely lose the benefit of much of the pipe surface installed.

While it is impossible in the scope of this chapter to discuss the design, construction, installation, and operation of the machinery, it is nevertheless of the very greatest importance. Effort is frequently made to operate an expensive plant with low-paid mechanics, who do not understand the machinery, either in theory or practice. Naturally the results are highly unsatisfactory. In the smaller plants automatic machines are often used (i.e., plants controlled by thermostats in the cold rooms which stop and start the machinery as necessary to maintain the desired temperature). However, few machines other than those of the ammonia compression or absorption type are used for fish freezing.

For the technology of refrigeration machinery reference should be made to the numerous books on the subject.

Preliminary Handling Aboard Boats

On small inshore boats the catch of fish usually receives no preliminary chilling, but is covered by tarpaulins or other covering and brought ashore. Many

species of fish, including salmon (ocean-caught), lake trout, halibut, cod, and haddock, are gutted on the boats because of the danger of intestinal putrefaction. Species in which this is not so likely to occur are usually brought ashore "in the round" (i.e., not gutted or beheaded). In fact, for purposes of freezing it is better not to gut or behead the fish. When the boats remain out for some days, crushed ice is carried; as the fish are caught, they are gutted and packed in the ice. In the halibut and salmon fishery of the northwest coast the heads are left on to prevent the leaching out of the cut surfaces that would otherwise occur on exposure to melting ice. The heads are removed on arrival of the fish at the freezer. In the preliminary icing it is important that the ice be crushed fine so as not to bruise the fish. The fish should be placed in ice immediately and the poke or belly cavity filled with ice. Care should be taken that the fish are not packed too deep as those in the bottom of the pile may be partly crushed. Bruising or crushing greatly accelerates autolysis. Glacier ice is sometimes used in emergency in Alaska, but is very unsatisfactory and should be avoided. Sometimes a boat may remain out 2, or even 3 weeks. In such cases the fish caught earlier on the trip are in exceedingly poor condition—soft, blanched, and even sour. Such fish should not be frozen.

In the public warehouse freezers the handling of fish previous to arrival is beyond the control of the freezer. The fish are usually in boxes or barrels in which they have been delivered or shipped, and are of unknown history.

Landing, Inspecting, and Grading

In the case of fishing boats the fish, on arrival at the freezer, are usually landed by an electric hoist. Halibut are generally hoisted in a large net bag, made of ½-inch Manila rope. Though highly efficient, this bag bends the fish and the ropes bruise them. Better means are used for salmon; for example, strong boxes are lined with galvanized iron and provided with rope handles at the ends, like a trunk. The two ends are outwardly inclined so that when the contents are dumped, they slide easily and gently on the floor from the inclined ends, bruises being thereby avoided. Pewing or forking, though sometimes resorted to, is extremely objectionable and should not be practiced. Even when a single tine pew is used and stuck in the head, frequent accidental wounds are made in the edible parts of the fish.

When the fish are landed, they are, in the case of halibut, first beheaded. The beheaders lift the fish by the head by means of a meat hook and strike off the head with a heavy butcher knife, one blow usually sufficing.

Inspection. If frozen fish do not occupy the place in public esteem that they should, it is mainly because of insufficient inspection and rejection of poor quality fish. The inspection should be directed to two objects: grading into sizes for the purpose of paying the fishermen (where necessary) and grading into quality for acceptability. The size gradings are too numerous and varied to be considered here. The quality grading, however, is of utmost importance in every lot of fish to be frozen and requires the skilled eye of an experienced judge of fish.

Washing and Panning

If fish are in the round, they are washed. If butchered, especially the high class fish such as chinook salmon, they are beheaded and the bits of kidney and

blood removed by hand, sometimes with the help of brushes. If the salmon are fat, running water is imperative to prevent the smearing of the fish with the accumulated bits of fat. In any fish the use of running water has been shown to be very important. Halibut, after being laid on the floor, white sides up, and with head ends in one direction, are washed by means of a hose. They may also be washed by turning a hose into the belly cavity or by being placed in water tanks. Smaller fish to be panned are washed in a long tank. Fresh water is most commonly used. Care should be exercised to get pure, wholesome drinking water, or pure sea water. Harbor water is unsafe as the fish are to be eaten.

Swordfish and sturgeon are butchered and cut into pieces of convenient size, usually about 2 feet long. Halibut and salmon go to the sharp freezer from the washing. Nearly all smaller fish are panned.

The panning tables are located adjacent to the washing tank. Often the tables are small shelves attached to the washing tank or to a draining trough.

The pans are of 20- to 22-gauge galvanized iron; the commonest size is 16 inches × 26 inches × 3 inches deep, holding from 25 to 40 pounds each. In any event they should produce cakes which will fit the final packing box. Some pans have a few holes in the bottom to permit drainage of water, slime, and blood. Usually the pans have sloping sides to facilitate removal of the frozen cake. However, if the pans have lids, the sides of the pans and lids are straight. Lids help to prevent the evaporation of moisture in the sharp freezer. The fish are placed in regular arrangement in the pans, the arrangement depending on the size and shape of the fish. It is a good plan to pack fish with their bellies exposed at least on one side; the belly side most readily indicates the condition of the fish. If the bellies are gassy, it is best to pack them inward so that the glaze does not come off readily. In order to make firm cakes it is desirable to pack the fish in the pans so that they press firmly together. Too close packing, however, makes separation of the cakes impossible.

The character of the skin has much to do with the solidity of the cake. Fish which have soft slimy skin, like catfish, eels, lake trout, etc., make substantial cakes, while fish with rough, stiff skin, like the blue and yellow pikes, make cakes that break up rather more readily. Skilled panners require from $1\frac{3}{4}$ to $2\frac{1}{6}$ minutes to pan Spanish mackerel in pans of the size described.

Pans used for freezing fish should be cleaned occasionally by scrubbing with hot water and a good scouring powder.

When the pans are packed, they are placed on trucks and carted to the sharp freezers.

Fillets and Steaks

In 1921 Dana Ward started filleting fish and packaging them for sale in the New England market. Haddock and cod fillets, being substantially boneless and free from waste, immediately became very popular. Other fillets which are now produced on a large scale include flounder, sole, pollock, rosefish or red perch, rockfish, whiting, dabs, hake, and cusk.

Fillets are obtained by cutting the flesh from one side of the backbone the length of the fish starting just behind the head, then turning the fish over and cutting a similar strip of flesh from the other side of the backbone. Some fillets are skinned, others marketed without skinning.

Larger fish, such as salmon, halibut, and swordfish, are not usually filleted, but are cut crosswise of the backbone into "steaks," each a little more than an inch in thickness. These steaks usually include 1 vertebra.

The demand for fillets and steaks during the late twenties gave great impetus to the freezing of packaged fishery products. Fillets and steaks absorb too much

(Courtesy General Seafoods Corp.)

FIG. 16–3. Filleting rosefish by hand.

salt when they are frozen by immersion in or spraying with brine, consequently many new quick freezing systems were invented which make it possible to freeze packaged products rapidly (p. 349).

Since fillets and steaks are difficult to glaze satisfactorily, it became necessary to perfect both wrappers and packages which would retard desiccation and oxidation during freezing and storage. Ordinary vegetable parchment, cellophane, and waterproof papers do not disintegrate in water, but permit so much moisture-vapor to pass through them that frozen fish fillets wrapped therein desiccate and oxidize rapidly. For this reason, sheetings used for wrapping fillets for freezing must be specially coated to make them moisture-vapor-proof.

Filleting. The layout of a filleting plant and the methods used in handling the fish and fillets will vary from place to place; however, a description of operations may be helpful.

The fish, which have been eviscerated and packed with ice in bins at sea, are hoisted out of the hold of the vessel in canvas baskets holding approximately 100 pounds. The fish are dumped into a tank of running chlorinated water in

which they are washed to remove slime, blood, and ice. If the fish are being received faster than they can be filleted, they are removed from the tank by an automatic conveyor and packed in crushed ice in hinged boxes, each of which holds about 600 pounds of fish. These large boxes of fish are trucked to a room, maintained just above freezing, where they are held until needed for filleting.

As soon as the fish can be filleted, the boxes are emptied into the hopper of a scaling machine in which the scales are removed and the fish washed with sea water. From the scaler the fish pass through washing tanks and thence to a rubber belt conveyor to the workers who cut a fillet from each of the two sides of the fish, remove any large bones from the fillets, and put them in corrosion-resistant pans. In some plants filleting machines are used.

Skinning. A large proportion of the fillets are skinned prior to packaging. In the smaller plants and also in many large plants the skinning is done by hand by the men who do the filleting. To skin a fillet the operator places it skin side down on

(Courtesy Atlantic Coast Fisheries Co.)

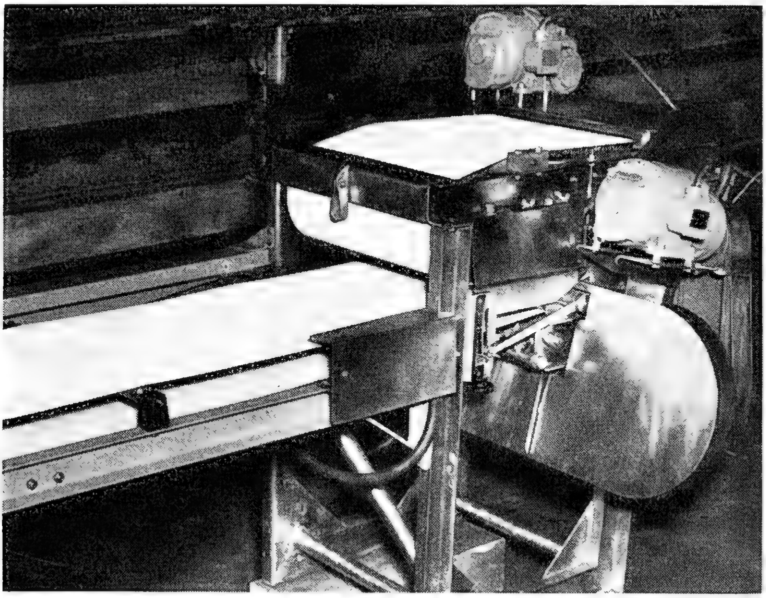
FIG. 16–4. Feeding haddock into Atlantic Coast filleting machine.

a table, grasps the skin of the tail end with his fingers, and cuts crosswise through the thin flesh (but not through the skin). Holding his knife almost horizontal, he then pulls the skin and cuts the fillet off of the skin.

Many different types of skinning machines have been tried, but until recently none has proved to be entirely satisfactory. The Jensen "Speedi-skinner," which was introduced in 1947, is now in use in several Pacific Coast filleting plants (Fig. 16–5). This skinning machine is a compact, self-contained unit, designed to serve as part of a belt-filleting line. The fish fillets are placed skin side down on the moving feed belt of this machine and move rapidly over a sharp, power-driven band knife. A second belt is placed so as to apply even pressure to the fillet and

hold it firmly in place as it crosses the knife, which slices off the skin without tearing or pulling apart the fillet. One machine will skin all of the fillets cut by 22 to 28 filleters (3000 to 4000 pounds per hour). One man is required to feed large fillets to the machine; two are needed for smaller fillets.

The machine is also designed to split thick fillets, such as those produced from the Pacific Coast rockfish. As split fillets are of uniform thickness, they are better



(Courtesy Jensen Equipment Co.)

FIG. 16–5. Inlet end of Jensen fish-skinning machine.

suited for packaging in rectangular packages. Furthermore, they can be cooked more uniformly than the thick fillets (Stansby and Dassow, 1949).

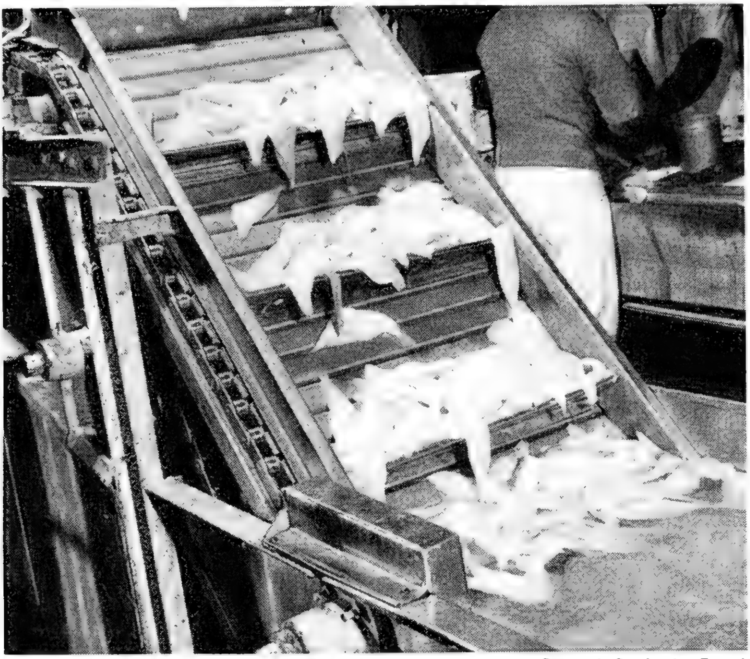
As the fillets come from the skinning machine, they are spread out on a conveyor where they are inspected and in some plants are sprayed with chlorinated sea water as they pass to a briner. They are then conveyed in 20 to 120 seconds through a brine containing 3 to 15 per cent salt and a few parts per million of sodium hypochlorite.

Brining. The lower the concentration of brine used, the longer the period of immersion required to prevent drip. Thus, if a 10 to 15 per cent brine is used, only 20 seconds immersion is required; whereas, if the brine contains only 3 per cent of salt, the brining period may be as long as 2 minutes.

Pure salt solutions are more effective in preventing drip than brine relatively high in calcium and magnesium salts and sulfates (Tressler and Murray, 1932). Furthermore, fillets treated with pure brine retain their good flavor much longer than those dipped in impure brine. Tarr (1941) concluded that the action of the brine is not purely superficial, but the salt slowly penetrates the tissues causing them to swell and bind the liquid tightly.

Taylor (1933) suggested the use of an alkaline solution containing nitrites as

a dip for fillets in order to prevent drip after thawing. The alkaline dip modified the pH of the fish tissues so as to increase their water-holding capacity. Alkaline dips are not commonly used, but nitrites are used by many Canadian fish packers



(Courtesy General Seafoods Corp.)

FIG. 16–6. Conveyor removing fillets from brining machine. Brining fillets reduces the amount of drip or leakage which appears when the frozen product is thawed.

to lighten the color of the fillets. Nitrites also possess antiseptic properties. Consequently, fillets dipped in nitrite solutions will not spoil quickly because of bacterial growth.

Packaging Fresh Fillets. The brined fillets drain as they are conveyed to corrosion-resistant pans, in which they are carried to packing tables.

Many different types of packages and wrappers are used for fillets. Iced fillets, marketed without freezing, are commonly individually wrapped in vegetable parchment paper and then packed in rectangular 30-pound japanned or tinned metal fillet cans, having slipcovers. Some fresh fillets are packed in 5-, 10- or 20-pound waxed paperboard or fiberboard cartons, usually fitted with telescoping covers.

Chilled fillets of very high quality are produced by quickly cooling the packages with rapidly moving air at about 0° F (– 18° C) in an air-blast tunnel. The fillets are kept in the tunnel until ice crystals begin to form, at which point the temperature of the fillets has been reduced to 28 to 30° F (– 2.2 to – 1.1° C). The containers of fillets are then packed in fiberboard boxes and rushed to market. Fillets which have been quickly chilled in this manner and then shipped by air

or for short distances by truck reach their destination in excellent condition and command a premium price. The containers of fillets are kept as close to 32° F (0° C) as possible until the fillets are sold at retail. This is usually accomplished by packing them with crushed ice in large wooden boxes.

After being individually wrapped in moistureproof vegetable parchment or cellophane, fillets are sometimes packed in 10-, 20-, or 30-pound wooden boxes for "sharp" freezing. Heavily waxed folding cartons, holding 5 or 10 pounds of individually wrapped fillets, are commonly used for quick freezing by the "Birdseye" and other processes. After being frozen, a number of these waxed paperboard cartons are packed into a corrugated fiberboard container for storage or shipment.

The One-Pound, One-Piece Package

Under a process invented by Harold E. Crowther and Lawrence T. Hopkinson, assigned to the Atlantic Coast Fisheries Company, a commercially acceptable one-pound, one-piece package of cod, haddock, and pollock has been developed. In this process the skinned fillets are laid lengthwise in a moving trough, measuring 4 inches wide and ¾ inches deep. The trough passes under rollers which level out the fish without exerting any substantial pressure, thus avoiding the breakdown of tissue.

The moving trough actually consists of segments, each segment measuring 8 inches long, mounted on a belt. The belt moves around pulleys and at the breaking point the ribbon of fish is cut crosswise, thus producing a piece of fish measuring 4 inches wide × 8 inches long × ¾ inch thick. As the segments come off the moving belt, they fall into waxed cardboard trays, which in turn go through an automatic wrapping machine. The final product is frozen. On defrosting and cooking it remains in one piece.

The advantage of this product to the housewife is primarily in the matter of cooking. When baked, broiled, or fried all parts of the fish are evenly cooked, whereas in the case of an ordinary fillet the thin end must be overcooked to get complete cooking of the thick end. Another feature of the one-pound, one-piece package, having the dimensions referred to above, is that it fits conveniently in the ice-cube compartment of an ordinary household refrigerator.

Freezing Whole Fish

Sharp Freezers. As previously stated, the sharp freezer is a room which is usually much smaller than a cold storage room. It is preferably located so that its walls adjoin other cold rooms rather than outside walls, and has doors opening through anterooms so that the cold air cannot circulate with the outside air. The refrigeration pipes are arranged vertically on 8-, 10-, or 12-inch centers and horizontally on 4-, 6-, or 8-inch centers in banks of shelves. These dimensions depend on the chosen ratio of piping, on the size of fish or pans, etc.

Panned fish are placed on the pipes. In public freezers the first and last pan of each lot may be marked with a slip of paper to indicate the lot. If large fish, such as salmon, halibut, sturgeon, swordfish, etc., are frozen, the shelves must be farther apart and covered with sheets of 14-gauge galvanized iron. The fish are either laid on shelves, or else, as is done in some places, on the floor or on slatwork along the floor. In some well-systemized plants 2 or 3 men are assigned to a particular room at each loading; a record is kept and the men are held personally responsible

for putting in the fish straight. If large fish are thus loaded in, they must not overlap so much as to freeze together.

In large sharp freezers and especially where brine is circulated through the pipes there is a comparatively large reserve of refrigeration in the brine, pipes, and air. Consequently, a comparatively large quantity of fish can be placed in the rooms without excessive rise in temperature. Since the rate of extraction of heat from a body is proportional to the difference of temperature between it and its surroundings, it is evident that fish will freeze more rapidly if placed in a cold room than they will if placed in a room which is warm at the start. The temperatures often available in such large rooms (i.e., rooms of 60,000-pound capacity) range from 0 to − 12° F (− 17.8 to − 24.4° C), which not only makes possible a relatively well-preserved fish, but also shortens the time of freezing.

The small individual freezer is, however, more popular, especially where direct expansion is employed. There are usually several rooms, side by side, each of a capacity of from 12,500 to 30,000 pounds. While such a room is being filled with a large quantity of fish, the temperature rises rapidly to 15 to 35° F (− 9.4 to 1.7° C), though lower temperatures often prevail on completion of loading. When the room is filled, the door is closed and the expansion valve opened. The temperature gradually falls as the heat is extracted. The lot is judged to be frozen when the room has reached a temperature of about − 10° F (− 23.3° C). This figure not only varies from freezer to freezer, but in any particular freezer is subject to change with the exigencies of the day's rush. When there is no hurry, the room may be allowed to reach − 15 or − 20° F (− 26.1 or − 28.9° C), but if the freezer is needed for a fresh lot, the frozen lot may be taken out at 0° F (− 17.8° C).

The time required to freeze the different species of fish is usually not so important as might otherwise appear. The filled pans are almost always left in the freezer overnight (i.e., 24 hours or less). If the fish freeze in a shorter time, no advantage can be taken of the saving because the time for change would fall in the night. Large fish, such as halibut and salmon, are left in the sharp freezer over 2 nights (i.e., 40 to 48 hours). Very large fish may remain in the freezer 3 or 4 days.

The rate of freezing (i.e., the extraction of heat) is not uniform. When the charge is first put in the room, the temperature falls rather rapidly until freezing begins. A long period of little change in temperature ensues while the fish are freezing. Then there is a more noticeable lowering of temperature. In plants where ice tanks are cut off during the day, but are making ice at night, the influence of the heavier night load is also observable in the sharp freezers.

Defrosting of the pipes may be done by warming the room and flooding the pipes with warm liquid ammonia or brine, thus thawing out the ice which adheres to the pipes. Another method is to scrape the pipes with irons having a semicircular recess to fit the pipes. The former wastes refrigeration and is said to be very bad for the fish frozen immediately afterward because of the excessive dehydrating effect on the fish. Although the latter method is rather laborious, the fish are much less likely to dehydrate. In some plants the pipes are defrosted after each freezing, in others only once every 1 or 2 years.

Brine Freezing. When fish freeze slowly, the water contained in the muscle plasma and blood separates out and freezes as crystals of pure water ice. The

slower the freezing, the larger the crystals. When the fish are defrosted, not only is the juice, containing flavoring matter, lost, but the fish spoil much more rapidly in consequence of the damage done to the cellular structures by the ice crystals. These changes seriously limit the frozen fish business. Therefore, the principal steps taken to improve freezing methods aim at securing more rapid freezing.

Brine is a much better conductor of heat than air, and has a much greater specific heat. Therefore, fish immersed in brine of about 0° F (− 17.8° C) will freeze very much faster than in air at the same temperature. Although substances other than salt have been proposed (e.g., glycerin, alcohol, magnesium chloride, etc.), salt is the only substance used so far which answers all the requirements of freezing point, low price, and palatability.

In Norway some fish are frozen in brine, made by mixing salt and crushed ice according to a method invented by Nekolai Dahl. This procedure simply involves the pumping of brine around the fish packed in shipping boxes.

Brine freezing of fish was introduced into the United States in 1918, but has never attained general usage. From the standpoint of flavor the quality of brine-frozen fish is high, although their exterior, which is in contact with the brine, may be a little salty. One reason why brine freezing has not been generally used in this country is that the method is not adaptable to the freezing of fillets and steaks.

The introduction of brine freezing and the somewhat later introduction of filleting (about 1925) into the United States acted as a spur to research on other rapid methods of freezing which quickly remove heat without direct contact of the fish with the brine. These methods of quick freezing will be considered in detail later in this chapter.

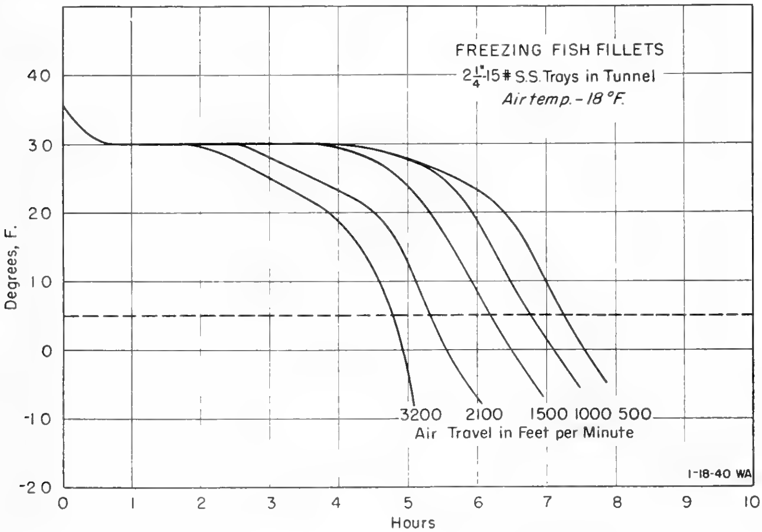
The "Z" Method. M. T. Zarotschenzeff developed a brine-freezing process in which the fish or other foods are frozen in a spray or "fog" of sodium chloride brine. Three different types of apparatus have been devised by Zarotschenzeff. One consists of a cabinet with a number of separate compartments in which are placed wire mesh trays filled with the product to be frozen by the spray of refrigerated brine atomized from properly located nozzles. The second type of "Z" freezer is a large chamber or tunnel into which are pushed trucks loaded with trays of the product and sprayed with the refrigerated brine. The third type of apparatus consists of a wire mesh belt conveyor which transports the product through a tunnel in which the refrigerated brine is atomized. The brine which collects on the bottom is refrigerated, recirculated, and atomized. The usual temperature of the spray is 0 to − 3° F (−17.8 to − 19.4° C).

The University of Texas Polyphase Quick Freezing System, also known as the "Bartlett Freezer," has been devised for the rapid freezing of shrimp, although it is also used to a limited extent for freezing other foods. Bartlett and Woolrich (1942) describe this freezer as follows: It consists of a refrigerant-jacketed horizontal tube, partly filled with the polyphase medium, inside which a closely fitting helicoid conveyor operates. This tube terminates in feed and discharge compartments which are connected by a return conduit. The discharge compartment is equipped with a suitable grid which is periodically traversed by a raking device. A circular oscillation is superimposed upon the normal rotation of the conveyor screw to provide the necessary agitation. This motion removes the fluid film and

the freshly formed ice crystals from the refrigerated surfaces, thus materially increasing heat transfer. A suitable mechanism regulates the rate of travel through the tube to allow complete freezing of the various sized particles. After the desired chilling has been accomplished, the food is removed from the body of the medium and allowed to drain in a refrigerated compartment. A very slow agitation during this step of the process facilitates the removal of the adhering fluid. If desired, a more vigorous means, such as an air blast, may assist the gravity draining (Bartlett and Woolrich, 1941).

For a detailed account of the various other brine-freezing processes, the reader is referred to the first edition (1923) of "Marine Products of Commerce."

The Petersen Freezer. According to the Petersen method, which is used in freezing some fish in the Great Lakes Region, the fish are frozen singly or in blocks in deep, elongated, narrow metal cans placed in tanks of calcium chloride brine at − 20 to − 30° F (− 28.9 to − 34.4° C) in a manner similar to that employed in making ice. In order to handle fish of varying sizes several sets of different sized cans are employed. One common size produces cakes 2 inches thick, 28 inches long, and 18 inches wide. The frozen blocks of fish are removed by slightly warming the cans in water or brine above 32° F (0° C), after which the cans are inverted, permitting the block of fish to slip into the glazing tank.



(Courtesy Dewey and Almy Co.)

FIG. 16–7. Curves showing rate of freezing of fillets in air blasts of different velocities. The fillets were frozen in stainless steel trays, 2½" deep, in air at −18° F (−27.8° C).

Air-Blast Freezing. Freezing may be greatly hastened by the use of rapidly moving, intensely cold air. A cold air blast is usually obtained by directing air from a blower through coils refrigerated by ammonia, "Freon," or some other refrigerant. In the Pacific Northwest some panned fish and panned fillets are frozen in covered aluminum pans placed on movable racks or buggies in Frick

"Blizzard" and in York air-blast freezers. The "tunnel" will hold 2 trucks, each loaded with approximately 1,000 pounds of fish.

The temperature of the air used in freezing fish by the air-blast system is usually between -10 and $-20°$ F (-23.3 and $-28.9°$ C) although lower temperatures are sometimes used. The air velocity employed usually varies between 500 and 2,000 feet per minute; the greater the velocity, the more rapid the freezing (Fig. 16–7).

The Kolbe "Diving Bell" Freezer. R. E. Kolbe (1925) has developed 2 types of machines for freezing fish. The first, which is known as the "diving bell" system,

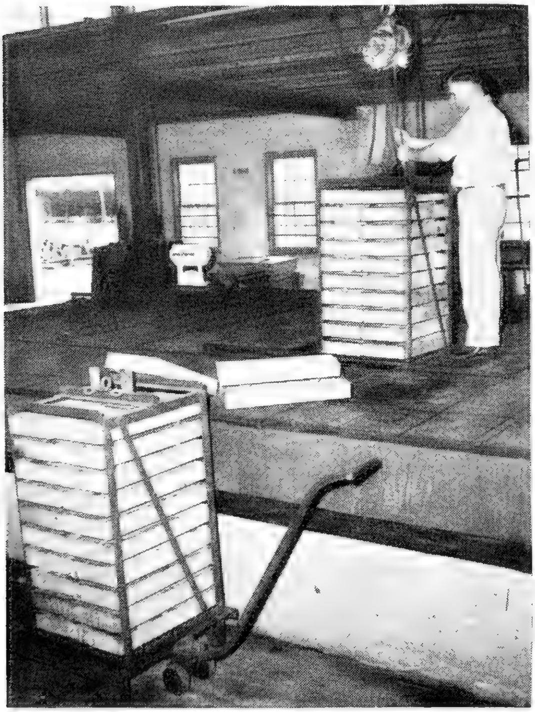


FIG. 16–8. Lowering a frame of Kolbe "Diving bell pans" filled with fish into the cold brine.

(Courtesy Union Fish Co.)

freezes fish in shallow metal pans fitted with telescopic covers. This is still in use. A number of these pans are placed in a frame and then lowered in a brine tank (Fig. 16–8). The brine is prevented from entering the pans by the entrapped air in the covers of the cans.

Kolbe's Floating Pan System. In 1927 Kolbe received a patent on a system of freezing individual fish or fillets in pans floating on brine in a trough of refrigerated brine. The pans are circular and about 20 inches in diameter and 3 inches deep. The usual form of Kolbe's apparatus consists of a shallow insulated brine tank with longitudinal baffles, alternately fitting close to one end and lacking about 2 feet of meeting the opposite end of the tank. Brine entering one end flows through this series of troughs formed by the baffles and carries the pans containing a single layer of fillets, steaks, or small fish. The system of troughs is so arranged that the pans start and complete their trip at the same point. The

temperature of the brine is usually maintained considerably below 0° F (− 17.8° C); the lower the brine temperature, the greater the capacity of the apparatus. Kolbe's system is a relatively simple way of freezing fillets, steaks, and individual fish.

Freezing Packaged Fish

Cold Plate Freezing. Refrigerated, thin, corrosion-resistant metal plates are often used for freezing foods in locker plants and small cold storages. Two common makes of these plates are the "Kold-Hold Serpentine Plates" and the "Dole Vacuum Cold Plates." "Freon-12," or some other primary refrigerant, is circulated through a series of plates. Because of the rapid conduction of heat from the food being frozen by the thin metal plate, rapid freezing is obtained. In some installations the rate of freezing is hastened still further by an air blast from a fan or blower. These plates may be used to freeze fish or fishery products either before or after packaging.

The Murphy Freezer. In 1933 Murphy designed a freezer in which the product is frozen on coils of refrigerated pipes of rectangular cross-section. These are arranged in shelves staggered one over the other to provide a sinuous passage for a cold air blast. Blower fans are placed at the ends of the chamber to force cold air over the product. Thus the products are frozen by conduction of the heat from the under side and by convection from the upper side. The cold air is circulated first over the bottom coil and then over the next one above and so on until it reaches the top cooling coils where it is refrigerated and returned through the system. The product to be frozen, either packaged or loose, is placed on trays which are then put on the pipe shelves.

"Birdseye" Systems. Clarence Birdseye developed 2 different types of freezing machines for freezing both fish and other products. The first is known as the double-belt freezer and the second the multiplate freezer. Although these machines are of entirely different design, the freezing is accomplished by the same principle—that of extracting heat by conduction through movable metal plates which exert pressure on the product being frozen.

The "Birdseye" double-belt freezer is used to freeze both round and packaged fish and fishery products. This freezer consists of endless corrosion-resistant metal belts running at the same speed and in the same direction through an insulated freezing tunnel. The usual length of the freezing area is 50 feet. The lower belt is usually 36 inches wide and the upper one 44 inches wide. The food to be frozen is placed on the upper side of the lower belt (which extends out beyond the upper belt) and is automatically engaged with the desired pressure by the upper belt and carried into the freezing zone. Calcium chloride brine, refrigerated to about − 50° F (− 45.6° C), is sprayed on the under surface of the lower belt and on the upper surface of the upper belt. The upper belt is wider than the lower belt so that the brine falls directly from its turned-down edges into a shallow tank under the lower belt. The double-belt freezer will take products of any thickness. As a rule the belts are not moved continuously; the freezer is filled with products to be frozen, then the belt is allowed to remain stationary until the charge is frozen. The belts are then operated until the frozen products have been moved out and a new charge put in. The double-belt freezers have been largely replaced by the more compact multiplate machines.

The "Birdseye" multiplate freezer was devised primarily for the freezing of foods packaged in rectangular paperboard packages. It is extensively used for the freezing of packaged fillets, steaks, and small fish. It consists of a number of superimposed refrigerated hollow metal plates, so actuated hydraulically that they will open to receive products between them and will close on the products with any desired pressure. The entire freezing apparatus, with the exception of the refrigerating unit, is enclosed in an insulated cabinet. As a rule the smaller freezers, 6 stations and less, are self-contained and have compressor, compressor motor, condenser, hydraulic lift cylinder, hydraulic oil tank, and pressure pump located directly underneath the insulated freezing chamber. The larger machines have separate refrigerating systems.

The plates of the earlier multiplate freezers were constructed of rolled aluminum alloy and provided with sinuous passages. Some of the more recent models have stainless steel plates which are much thinner than those of aluminum. This has the advantage that many more plates can be put in a freezer of any given height. A rubber hose is connected to a header which feeds each plate with the ammonia, "Freon," or brine used as the refrigerant. The other end of the plate is also connected by a rubber hose to another header which returns the ammonia or brine to the surge drum (in the case of ammonia) or to the refrigerating machine.

Most of the multiplate freezers have a hydraulically operated cylinder located under the bottom plate. As pressure is applied on the under side of the bottom plate, it lifts its load until it meets the second plate, which in turn is raised with its load, and so on up.

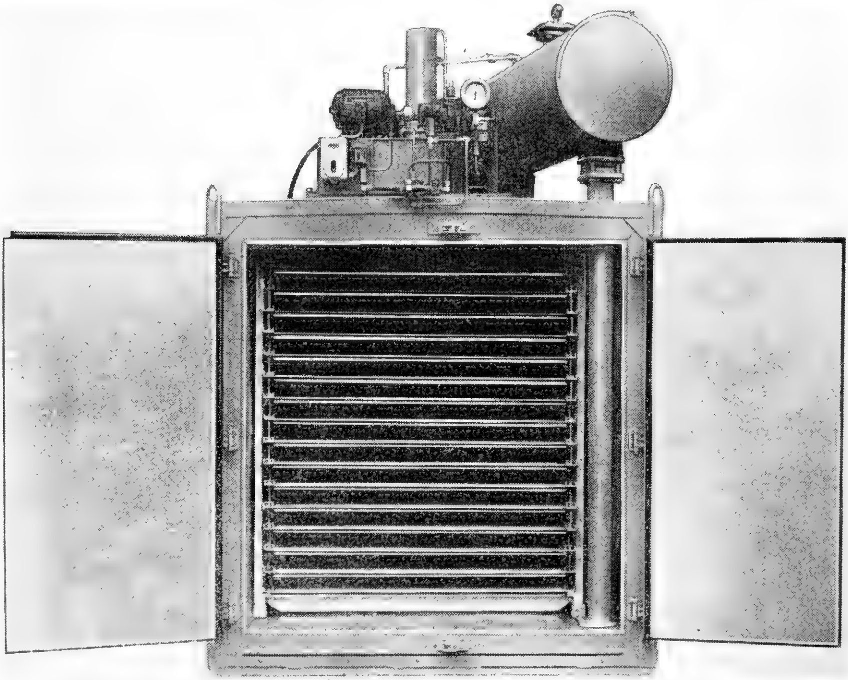
Before the packaged product to be frozen is placed in the machine, the plates are cooled to about $-28°$ F ($-33.3°$ C). The packaged products are placed on thin metal trays, which in turn are loaded into the freezer. Sticks of wood, as long as the plates and slightly less in height than the thickness of the packages being frozen, are placed on each side of the machine between each pair of plates to prevent crushing of the packages. The cabinet doors are then closed and the hydraulic pressure is applied to raise the plates and exert pressure upon the packages. As a rule the product is left in the freezer until the center of the packages reaches about 0° F. Of course the freezing time varies with both the thickness of the packages and the kind of food being frozen. Packages of fish fillets, 2 inches in thickness, require approximately 90 minutes to freeze.

The "Birdseye" multiplate freezer has a great capacity per square foot of floor space, far greater in this respect than the original "Birdseye" double-belt freezer. Further, the self-contained units are portable since they require only electric current and water connections for their operation.

The Jackstone Contact Freezer. Amerio Manufacturing Incorporated makes a multiplate freezer, designed by A. J. Stone, which closely resembles the "Birdseye" multiplate freezer. It consists of 16 Dole "vacuum" plates superimposed one over the other so as to give 15 freezing stations. The maximum opening of the plates is 3 inches; consequently, packages or products thicker than 3 inches cannot be frozen between the plates. In the closed position the minimum opening is 1 inch and wrapped fillets or packages thinner than this cannot be frozen.

The refrigerant system used is the "flooded" type. The surge drum is located on top of the freezing cabinet. The freezer is supplied ready to be hooked up to

(1) an ammonia line, (2) a "Freon-12" line, or (3) a refrigerated brine line. The machines are equipped with an accumulator, which is an automatic device for maintaining the packages on the plates under uniform pressure. This pressure may be adjusted to any point between 1 and 10 pounds per square inch; the usual pressure on the packages is 4 pounds per square inch. Even though an automatic



(Courtesy Amerio Inc.)

FIG. 16–9. Jackstone plate or Amerio plate freezer.

device is provided to maintain controlled pressure on the packages, wooden spacers ⅛ inch less in thickness are provided along 2 edges of the plates. This permits the freezing of products in relatively flimsy packages. The plates are raised and lowered and the pressure is applied to the plates by means of a hydraulic jack which has a 6-inch I.D. cylinder.

The freezers are all of sturdy construction. The outer frame is independent of the inner one, and is constructed of 6-inch steel I-beams. The outer case is constructed of 18-gauge sheet steel. The inner freezer frame has 4 steel uprights, each of 3-inch channel steel. There is 6 inches of lightweight "Fiberglas" between the outer sheet steel and the freezer proper. The double doors which open out are insulated with 5 inches of lightweight "Fiberglas."

"Jackstone Roto Froster." Another freezer for fish, which freezes by conducting heat simultaneously from both sides, has been invented by Stone. This freezer, known as the "Jackstone Roto Froster," consists of an insulated cabinet containing 24 pairs of freezing plates, which are mounted in a substantially parallel position and radiate out from and are attached to a revolving drum axis. As the drum

rotates, a pair of plates arrives at the loading slot and automatically spreads apart. A tray-full of products to be frozen is placed between the plates. As the loading door shuts, the drum rotates bringing another pair of the plates in the loading position. When the "froster" has been completely loaded, the first plate to be loaded has made a complete revolution, and during that period the product on it should be frozen. The tray of frozen product is removed and a tray of unfrozen product takes its place. As a rule the actual freezing operation is continuous; the speed of the rotation of the drum is regulated according to the time required for freezing the products.

Freezing Fish at Sea

As has already been indicated, fish deteriorate very rapidly after capture, even if held at 32° F. If the fish are caught on vessels at a considerable distance from shore and held for several days prior to landing, they will be rather stale, even though kept packed in ice. The ideal way to handle fish which must be held in ice for longer than a day or two is to freeze them on shipboard promptly after capture.

Prior to World War II the French (Lemon and Carlson, 1947) operated a fleet of several trawlers on which fish were frozen in the North Atlantic, North Sea, and Mediterranean. The Reeh system of brine freezing was used. The freezing unit consisted of a cylinder, about 8 feet long and 4 feet in diameter, revolving around a longitudinal axis. Each cylinder was divided by perforated partitions, thus forming 8 compartments. The drum (cylinder) was filled to the axis with circulating refrigerated brine. Each compartment was fitted with a watertight door, kept closed when the drum was rotated. Each vessel had a brine tank holding 21 tons of saturated sodium chloride brine which was cooled to approximately 10° F (− 12.2° C) by evaporator coils in the tank. A centrifugal pump was used to circulate the brine through the freezing drum and the brine tank.

When caught the fish were sorted and placed in one compartment of the freezing drum which held 550 pounds. The door was then closed and locked and the drum rotated 45 degrees, thus immersing the fish to be frozen in the brine. The next compartment was opened, filled, and rotated, repeating the operation until the fifth compartment had reached the filling point in the cycle. The freezing cylinder was so located that, when the compartments had rotated through 225 degrees, the opening was in the cold storage room where the frozen fish were unloaded. The frozen fish were separated according to species, placed in net bags containing about 50 pounds, and stored in the refrigerated hold. From 1 to 2 hours were required to freeze the fish. The total freezing capacity of this trawler was 20 tons per day.

A number of the tuna-fishing vessels of Southern California immediately freeze each catch by placing the fish in tanks or "wells" through which chilled sea water 28° F (− 2.2° C) is rapidly circulated. When the compartment has been filled with fish, the chilled sea water is pumped overboard and freezing is effected by circulating concentrated sodium chloride brine at about 4° F (− 15.6° C). The fish are brought down to a temperature of about 0° F (− 17.8° C), then the cold brine is returned to a storage well and the fish held dry at approximately that temperature.

Tuna frozen in this way is used almost exclusively for canning. Some salt

penetrates the fish during freezing, storage, and transportation to the cannery. In an experimental study Godsil (1940) found that brine at 20° F (− 6.7° C) "pickled" the flesh of the tuna to a depth of 1¼ inches in 34 days and to an equal depth when the fish were held at 25° F (− 3.9° C) for 27 days. However, the salt leaches out during cooking, preparatory to canning, and is not considered objectionable.

In 1947 the ship, "Deep Sea," began operating in the Bering Sea. Though virtually a factory fishing vessel it can "quick freeze" 1500 pounds of fillets per hour and has a 0° F (− 17.8° C) storage capacity of 300,000 pounds in 8500 cubic feet of refrigerated cargo space in 2 holds, divided by a watertight bulkhead. This vessel cost approximately $500,000, is 140 feet long with a 26.8-foot beam, and has a speed of 12 to 14 knots. The "Deep Sea" has a crew of 32 men who will remain at sea for 2 or 3 months, or until the refrigerated cargo holds are full.

Another American factory ship, the "Pacific Explorer," took her maiden voyage in 1947 and returned with 2300 tons of frozen tuna. This vessel has 7 cold storage rooms with a combined capacity of 168,152 cubic feet, capable of holding 2350 tons of tuna. Seven freezers, totaling 38,602 cubic feet, are located on the second deck; 3 of these are blast freezers, 2 of which take a charge of 15 to 20 tons and the largest, 50 tons. In addition, 4 small air-blast freezers, each having a capacity of about 3 tons, are located on the cannery deck for freezing packaged fish. Facilities are provided for the filleting of fish prior to freezing and for the preparation and canning of crabmeat. Since the "Pacific Explorer" acts as a mother ship, she must provide the other fishing vessels with fuel, water, ice, fishing gear, and repair facilities. In addition, accommodations for nearly 80 persons are provided.

Glazing of Frozen Fish

Various methods have been practiced to prevent the desiccation, rusting, and loss of flavor to which frozen fish are subject during the period of storage. Wrapping with impervious paper, glazing, covering with wax or tallow, and freezing in ice blocks have all been tried. The simplest, cheapest, and most practicable method for whole fish is glazing, and, if properly done, answers all requirements.

Nature and Purposes of Glazing. If the fish, while frozen, are dipped into cold water and withdrawn into the air of a cold room, the adhering film of water freezes, forming a transparent envelope of clear ice surrounding and adhering firmly to the fish. The ice glaze at once brightens the colors of the fish and prevents all evaporation from the fish as long as it remains intact. It serves to retard rusting, but unless the storage temperature is sufficiently low, cannot altogether prevent it because the glaze gradually becomes porous. After glazed fish have been stored for some time, upon close examination it will be found that the ice envelope has many small holes through which the oil comes to the surface of the glaze.

Methods of Applying the Glaze. It is necessary that certain factors be taken into account for the best glazing. In the first place the glaze should be uniform. For some reason, for which no good explanation is yet forthcoming, if the water is too cold 32° F (0° C), the glaze will be pebbly. The water is usually from 34 to 38° F (1.1 to 3.3° C), but may be as warm as 50° F (10° C) and still apply a thin

but perfect glaze, provided the air of the glazing room is sufficiently cold. A glaze may be applied in a room having an air temperature from 28 to 32° F (− 2.2 to 0° C); however in that event, the adhering film of water gives up its heat to the fish, instead of to the surrounding air. Since the thinner parts—the fins, snout, and tail—have not sufficient heat capacity to freeze the glaze, these parts are not glazed under such conditions. It is far better to do the glazing in a room of sufficiently low air temperature so that the adhering water film, in freezing, gives up at least part of its heat to the surrounding air. When glazing is done in this way, the fins, tail, and snout are perfectly glazed.

There is some difference of opinion on the question of the proper temperature of fish at the time of glazing. When a fish comes from the sharp freezer, its temperature may be − 10 or −15° F (− 23.3 or −26° C), and is to be stored at about 5° F (− 15° C) (or higher). If the glaze is applied while the fish is at − 10 or − 15° F (− 23.3 or − 26° C), on subsequently warming up to 5° F (− 15° C) in cold storage, it is believed that expansion will crack the glaze.

The cakes of frozen fish are removed from pans by showering the latter, while inverted, with tap water, and a blow with a stick may then be necessary to dislodge the cake. A trough, 12 or 14 feet long by 2 feet wide and 12 inches deep, containing water, then receives the cake at one end. The succeeding cakes push one another along, and are taken out at the other end of the trough. They remain in the water from ½ to 1 minute. In other places a much shorter trough is employed and a much briefer immersion is practiced. The room in which this glazing takes place should be at a temperature of 12 to 15° F (− 11.1 to − 9.4° C). The cakes are then weighed, boxed, and stored, or else stored without boxing. In some freezers a movable glazing trough is taken into the storeroom and the cakes are glazed and stored immediately.

During glazing the fish gain in weight, the gain depending on the number of dips, the temperature of the air and water, the duration of dips, and above all, whether the fish are in cakes or not. Cakes of about 30 pounds, dipped once in water at about 34° F (1.1° C) and allowed to remain in the water 1 minute, take a glaze equal to about 4 to 7 per cent of the weight of the fish.

Large fish, like halibut and salmon, are glazed in an apparatus which consists of a wooden tank and wooden framework, capable of being lowered into the tank by a windlass, lever, or other such mechanism. The fish are trucked from the sharp freezer to the glazing room, and are put on the frame. The frame is then lowered several times (usually 3), each immersion being of only 5 or 10 seconds' duration. The fish are then returned to the same or another truck and conveyed to the storeroom.

An improvement on this method is a concrete tank below the floor level, into which a strong basket of angle iron and heavy wire gauze is dipped by means of a half-ton electric hoist. The basket is taken to the sharp freezer, loaded, and trucked to the glaze room, where its contents are glazed. Then, still without being emptied, the basket is returned to the truck and conveyed to the storeroom where it is emptied. This method makes it possible to do all operations without repeatedly handling each fish, and also works with larger quantities. In these glazing tanks little attention is paid to the temperature of the water as long as the glaze is not pebbly, or the water too warm to glaze at all. Of course, ice accumulates heavily on these tanks and must be cleaned off.

When fish are in storage, it is sometimes necessary to glaze them repeatedly.

If in cakes not boxed, the fish may be readily glazed in a trough brought into the storeroom. Boxed fish may also be immersed in tanks, box and all, and so glazed. Fish that are not in cakes and not boxed may be sprayed with cold water with an air brush or sprayer, such as that used for whitewashing or for spraying shrubbery and trees. The adhering water freezes quickly. The glaze may be applied as frequently as necessary.

For successful glazing, the following points should be observed:

(1) The water should be at a temperature between 34 and 40° F (1.1 and 4.4° C).

(2) The temperature of the air, if in a separate glazing room, should be at about 12 or 15° F (− 11.1 to − 9.4° C).

(3) A series of dips is better than one prolonged dip.

Cold Storage

If the success in the refrigeration of fish depends more upon one part of the process than in any of the others, that part is the storage. It is not that conditions are more unfavorable, but that harm is much more likely to develop during slow changes.

Placing Fish in Storage. Large unboxed fish, such as large quantities of salmon or halibut, are stacked in the rooms. When large quantities of fish are stored, the room is filled up to the ceiling in such a way that the fish do not quite come against the floor and side walls. Either a slatwork on 2-inch × 4-inch timbers covers the floor, and a similar framework is on the side walls, or else a corridor 18 inches to 20 inches wide is left between the walls and the stack of fish. This arrangement permits access for reglazing by spraying. In stacking the fish the tail end is inside the pile, the shoulder end outside.

When fish are boxed, the boxes are stacked in close formation. Salmon and halibut are sometimes wrapped in parchment paper before being boxed. Although the boxes are costly, they keep fish well and retard desiccation and rust. However, fish can be kept as well without boxes. Fish are usually less frequently stored in boxes in private freezers than they are in public freezers and warehouses. Public warehouses are at a disadvantage in storing fish because they rarely have one lot large enough to fill a room, and the fish must therefore be separated into lots; the consequence of storing by lots is that much more surface is exposed, rusting and desiccation do much more damage, and the capacity of the storerooms is greatly reduced.

Boxes make reglazing more difficult. If boxed fish are to be reglazed, the boxes must be opened or dipped into a tank of water, either method involving considerably more labor than spraying. Perhaps the most serious objection to storing in boxes is the very much smaller amount of fish that can be stored in the rooms as compared with the storage of unboxed fish.

When fish are frozen in pans, the cakes may either be boxed or stacked unboxed in the store room. If the cakes are stored without boxing, care must be exercised to avoid breaking tails and snouts in handling. Boxed cakes should be stood up edgewise, not flat, so that any cakes that may not be fully frozen can freeze by a circulation of air between them.

Desiccation and Rusting. The loss of moisture and development of rust are the great enemies of stored frozen fish. The preventives are simple, namely, packaging or glazing and low temperature. *The temperature cannot be too low.* A

temperature of 5° F (– 15° C) is better than 10° F (– 12.2° C), but rust will occur; 0° F (– 17.8° C) is still better and – 5° F (– 20.6° C) is good. At – 10° F (– 23.3° C) very fat salmon, if kept thoroughly glazed, may be kept for months with little or no signs of rust. Although low temperatures are more expensive to maintain than high, the difference in cost is made up in the better quality of the stored fish and the diminished losses; at least, numerous freezers find it to their advantage to maintain the temperatures mentioned.

Dry wooden boxes absorb moisture; they should be thoroughly wet before the fish are packed in them for storage. Frequent defrosting of pipes is said to promote drying out of fish. The fish which are exposed on the outside of each lot, especially in proximity to cold pipes, dry out faster. Freshly whitewashed walls promote desiccation.

Fat fish are much more susceptible to rusting than lean fish, and particular precautions should be taken in storing them. Salmon, lake trout, mackerel, etc., should be placed in the coldest room. Halibut, whiting, flounder, and other leaner fishes can stand a higher temperature, but very low temperatures do not damage them.

There is no cure for fish once they are rusted. Sometimes, their appearance is improved by taking them from storage and scrubbing them with a stiff brush, wet with warm water (about 100° F [37.8° C]) in which some ordinary baking soda is dissolved. The brush should be narrow enough to reach into crevices. The fish are rinsed in another tank of warm water without soda, returned to the sharp freezer a few hours, reglazed, and returned to cold storage. However, the fish are never as good as they would have been if rusting had not occurred.

Fluctuation of temperature promotes desiccation. Rooms, once filled, should be disturbed only for inspection and reglazing; lights should be kept off and the temperature held as low and as constant as possible.

Fish "in the round" (i.e., as they come from the water, neither gutted nor beheaded) keep better, rust less, and in general are more suited to freezing and storage than dressed fish. This point does not seem to have been investigated sufficiently, however, and a suspension of judgment may be justified until further research is carried out.

For successful storage the following points should be observed:

(1) Fish should be thoroughly covered with a uniform glaze before storage, and glazing should be repeated as often as necessary by dipping or spraying.

(2) The storage temperature should be – 5° F (– 20.6° C) or lower for fat fish, and is preferable for any fish. Temperatures as high as plus 5° F (– 15° C) are permissible for leaner fish only *for a limited time.* The temperature cannot be too low.

(3) The temperature in the cold storage rooms should be held constant, lights cut off, and doors kept closed.

(4) Unless circumstances make it necessary, fish should not be butchered for freezing, but should be frozen and stored "round." If stored gutted, the glaze should be perfect and the temperature held very low to prevent rust.

Packing and Shipment

Fish that were boxed before storage may be shipped as they are and those that have not been boxed must be boxed before shipment. Before being boxed any

culling for size should be done. Some shippers first wrap the fish in parchment paper, which somewhat retards defrosting and rust and gives the packages a better appearance. Boxes should be filled as full as possible to prevent abrasion due to shifting of the contents. No ice is put in the boxes. About four-fifths as many pounds of small fish can be packed in a box when individually frozen as when frozen in cakes.

Winter-caught fish (fish that have been caught in very cold weather, principally in Canadian lakes, and allowed to freeze in the cold air on the ice where they are caught) are often packed, in snow. This protects them against damage in shipment, and prevents desiccation. While the fish are in the snow, however, they are not so readily seen and judged for quality.

REFERENCES

Anon., "New Method of Quick Freezing (Murphy)," *Ice and Refrig.*, **91**, 457–458 (1936).

Anon., "New Gloucester Fish Pier Freezer," *Ice and Refrig.*, **96**, 511–513 (1939).

Anon., "Modern Refrigerating Plant Stored Huge Supply of Perishable Foods," *Ice and Refrig.*, **99**, 267–268 (1940).

Anon., "New Type of Quick Freezing Unit (Jackstone)," *Ice and Refrig.*, **100**, 313–314 (1941).

Anon., "New Quick Freezing Unit Developed (Blizzard)," *Ice and Refrig.*, **101**, 127–128 (1941).

Anon., "American Voyager's 117-Day Trip Is Refrigeration Epic," *Pacific Fisherman*, **39**, No. 8, 21–22 (1941).

Anon., "Notes on the Application of Refrigeration to the Australian Fishing Industry," *Australian Council Sci. Industrial Research Circ.*, 4 **P** (1942).

Anon., "New Freezer for Florida," *Fishing Gazette*, **61**, No. 8, 84, 90 (1944).

Anon., "Refrigerated Factory Ship Processes and Packages Seafood," *Refrig. Eng.*, 54, 127, 178 (1947).

Anon., "Quick Freezing Puts to Sea—the New Burney Freezer," *Modern Refrigeration*, **50**, 294–295 (1947).

Anon., "Whitefish for Quick Freezing," *Food Manufacture*, 23, 582 (1948).

Anon., "New Type Fish Briner," *Fishing Gazette*, **65**, No. 13, 46, 49 (1948).

Anon., "Standards for Quick Frozen Fish," *Modern Refrigeration*, **51**, 271–272 (1948).

Anon., "Uses of Ascorbic Acid in Frozen Fish Products," *Quick Frozen Foods*, **11**, No. 3, 66–67 (1948).

Anon., "First Refrigerated Sardine Carrier," *Fishing Gazette*, **65**, No. 8, 58 (1948).

Anon., "New Fish-Skinning Machine," *Fishing Gazette*, **65**, No. 6, 39 (1948).

Anon., "Fish Frozen on Floating Plant," *Quick Frozen Foods*, **10**, No. 9, 86 (1948).

Anon., "The Freezer Ship 'Pacific Queen,'" *Pacific Fisherman*, **47**, No. 8, 23–25 (1949).

Anon., "Universal's Fillet Briner," *Fishing Gazette*, **66**, No. 3, 50 (1949).

Banks, A., "The Freezing and Storage of Fish," *Modern Refrigeration*, **51**, 101–102 (1948).

Bartlett, L. H., and Broun, H. E., "A New Quick Freezing System," *Refrig. Eng.*, **42**, 83–87 (1941).

Bartlett, L. H., and Woolrich, W. R., "Polyphase Freezing Process Developed; Low Cost Unit Built. Part I," *Food Industries*, **13**, No. 12, 60–62, 103 (1941).

Bartlett, L. H., and Woolrich, W. R., "Polyphase Freezing Process Developed, Low Cost Unit Built. Part II," *Food Industries*, **14**, No. 1, 62–64 (1942).

Bauernfeind, J. C., Smith, E. G., Batcher, O., and Siemers, G. F., "Retardation of Rancidity in Frozen Fish by Ascorbic Acid," *Quick Frozen Foods,* **10,** No. 8, 139–142, No. 9, 68–72 (1948).

Beard, H. R., and Hedreen, C. A., "Preserving Foods Such as Fish and Other Seafoods," U. S. Pat. 2,151,967 (1939).

Bedford, R. H., "A New Ice Glaze for Frozen Fish," *Ice and Refrig.,* **90,** 217–218 (1936).

Bedford, R. H., "Frozen Foods Such as Fish," U. S. Pat. 2,214,398 (1940).

Bérubé, L., "Modern Practice in Preservation of Fish by Cold," *Food Industries,* **9,** 645 (1937).

Bucher, D., Heerdt, M., Jr., and Osterhaug, K., "Bibliography of the Preservation of Fishery Products by Freezing. Part I. Period to Jan., 1945," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **265** (1947). "Part II. Jan. 1945 to Dec. 1947" (by J. Dassow), *Fishery Leaflet,* **265** (Reissued 1949).

Carlson, C. B., "S.S. 'Pacific Explorer.' Part 3. Below Deck Arrangements and Refrigeration Equipment," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **316** (1948).

Carlson, C. B., "Quality Control of Freezer-Ship Tuna," *Pacific Fisherman,* **46,** No. 5, 47–49 (1948).

Castell, C. H., "Keeping Time and Quality of Sea Food Fillets," *Western Fisheries,* **35,** No. 7, 34, 36 (1948).

Castell, C. H., "Effect of Nitrite on Reduction of Trimethylamine Oxide in Cod Fillets," *J. Fisheries Research Board Canada,* **7,** No. 7, 421–429 (1949).

Castell, C. H., "Refrigeration Temperatures and Keeping Time of Fresh Fish," Fisheries Research Board Canada, *Prog. Repts., Atlantic Coast Stations,* **44,** 8–12 (1949).

Costa, D., and Cannella, C., "The State of Preservation and Tendency to Decompose of Defrosted Fish in Comparison with Fresh Fish," *Ann. Chim. Applicata,* **30,** 402–412 (1940).

Cutting, C. L., "Thawing of Frozen Fish," *Modern Refrigeration,* **18,** 198–199, 206 (1940).

Ede, A. J., "The Calculation of the Rate of Freezing and Thawing of Food-Stuffs," *Modern Refrigeration,* **52,** 52–55 (1949).

Fellers, C. R., and Harvey, E. W., "Frozen Fish Fillets Used Successfully in Benzoated Brine Dip Experiments," *Fishing Gazette,* **57,** No. 6, 36, 44 (1940).

Finn, D. B., "Freezing and Storage of Fish," *Refrig. Eng.,* **32,** 141–143, 158 (1936).

Fitzgerald, G. A., "The Fisheries of New England—Economic Factors," *Am. Geog. Soc. Special Pub.,* **16,** 261–277 (1933).

Fitzgerald, G. A., and Conway, W. S., "Sanitation and Quality Control in the Fishery Industries," *Am. J. Pub. Health,* **27,** 1094–1101 (1937).

Godsil, H. C., "Conclusion and Summary of Detailed Progress Report No. 2 on the Refrigeration of Tuna," Calif. Div. of Fish and Game, *Mimeo. Rept.* (July 15, 1940).

Hartshorne, J. C., "Bacterial Population of Brining Tanks in Fish Filleting Plants," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **9,** No. 10, 1–6 (1947).

Hendrickson, H. M., "Tuna Boat Refrigeration," *Refrig. Eng.* **58,** 456–462, 465 (1950).

Jarvis, N. D., and Nilson, H. W., "New Technics in Commercial Preservation of Fish and Fishery Products," *Food Technology,* **1,** 556–560 (1947).

Kolbe, R. E., "Method of and Apparatus for Freezing Materials," U. S. Pat. 1,527,562 (1925).

Kolbe, R. E., "Freezing Method," U. S. Pat. 1,641,441 (1927).

Lantz, A. W., "A Fish Scaler Adapted from Equipment for Recovery of Flesh from Fish Trimmings," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **77,** 114–115 (1948).

Lemon, J. M., "Sea Food Refrigeration Comes of Age," *Fishing Gazette,* **55,** No. 10 (Ann. Rev.), 80–82 (1938).

Lemon, J. M., "Suggestions for Storing Frozen Fish," *Quick Frozen Foods,* **1**, No. 9, 15, 30 (1939).
Lemon, J. M., "Fish Refrigeration," Chap. 7, "Refrigerating Data Book and Catalog," Vol. 2, "Refrigeration Applications," 15–29, New York, Am. Soc. Refrig. Eng., 1946.
Lemon, J. M., "Lactic Acid as an Index of Keeping Quality of Frozen Fish," *Am. Inst. Refrigeration Proc. 30th Ann. Mtg.,* 58–61 (1941).
Lemon, J. M., "Handling Frozen Fish," *Western Frozen Foods,* **9**, No. 2, 3–4 (1947).
Lemon, J. M., "Packages that Sell Frozen Fish," *Food Freezing,* **3**, No. 4, 29–31 (1948).
Lemon, J. M., and Carlson, C. B., "Freezing Fish at Sea," *Refrig. Eng.,* **54**, 527–530, 580–581 (1947).
Lovern, J. A., "Fishery Industries of North America. Part I, Fresh and Frozen Fish," *Food Manufacture,* **23**, No. 4, 171–175 (1948).
Manns, R. E., "Refrigeration Equipment in Common Usage," *Pacific Fisherman,* **39**, No. 3, 23–25 (1941).
Mitchell, T., "Refrigeration at Sea," *Quick Frozen Foods,* **11**, No. 2, 46–47 (1948).
Nickerson, J. T. R., Goldblith, S. A., and Proctor, B. E., "A Comparison of Chemical Changes in Mackerel Tissues Treated by Ionizing Radiation," *Food Technology,* **4**, 84–88 (1950).
Pellissier, C. E., "Frozen Seafoods—New Consumer Acceptance Is Fostered by Packaging and Quality Product," *Ice and Refrig.,* **99**, 66–68 (1940).
Piettre, M., "Tests on Quick Freezing Applied to Large Cuts of Meat," *Food Industries,* **9**, 646 (1937).
Pollock, E. D., "Blast Freezing Plants," *Refrig. Eng.,* **48**, 16–19, 32, 56 (1944), and *Ice and Refrig.,* **107**, No. 2, 22–24 (1944).
Pottinger, S. R., "Storing Frozen Fish," *Quick Frozen Foods,* **10**, No. 5, 69–70 (1947).
Pottinger, S. R., "Packaging Frozen Fishery Products," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **324** (1948).
Pottinger, S. R., "Frozen Fish," *Modern Packaging,* **21**, No. 11, 120–123, 244 (1948).
Proctor, B. E., Nickerson, J. T. R., and Goldblith, S. A., "Effect of Refrigerated Storage at Various Temperatures on Chemical and Bacterial Contents of Haddock," *Refrig. Eng.,* **58**, 375–379 (1950).
Puncochar, J. F., "Freezing Fish at Sea for Later Thawing: Processing and Freezing Ashore," *Fishing Gazette,* **65**, No. 12 (Ann. Rev.), 206, 210 (1949).
Reay, G. A., "The Freezing and Cold Storage of Whitefish," *Food Investigation Board (Great Britain), Rept. for 1939,* 43–47 (1949).
Reay, G. A., "The Freezing and Cold Storage of Fish," *Modern Refrigeration,* **18**, 142–144 (1940).
Sigurdsson, G. J., "Comparison of Chemical Tests of the Quality of Fish," *Analytical Chem.,* **19**, 892–901 (1947).
Stansby, M. E., "Judging the Quality and Freshness of Fish by Organoleptic Methods," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **94** (1944).
Stansby, M. E., and Dassow, J. A., "Preparing Fish for Freezing," *Fishing Gazette,* **59**, No. 12, 24 (1942).
Stansby, M. E., and Dassow, J., "Storage Life of Whole and Split Rockfish Fillets," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **11**, 7, 1–8 (1949).
Stansby, M. E., and Harrison, R. W., "Preliminary Investigations of Methods for Freezing and Storing Fillets of Some Pacific Northwest Fish," U. S. Fish and Wildlife Service, *Spec. Scientific Rept.,* **15** (1942).
Stone, A. J., "The Jackstone Roto Froster," *Quick Frozen Foods,* **2**, No. 7, 16, 32 (1940).
Stone, A. J., "The Practical Side of Freezing," *Refrig. Eng.,* **41**, 252 (1941).
Tarr, H. L. A., "Formation of Drip in Fish Muscle and Its Control in Defrosted Fish," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **47**, 5–9 (1941).

Tarr, H. L. A., "Loss of Free Liquid on Heating Brined and Unbrined, Unfrozen and Defrosted Fillets," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **48,** 19–20 (1941).

Tarr, H. L. A., "Effect of pH and NaCl on Swelling and Drip in Fish Muscle," *J. Fisheries Research Board Canada,* **5,** 411–427 (1942).

Tarr, H. L. A., "Comparative Value of Germicidal Ices for Fish Preservation," *J. Fisheries Research Board Canada,* **7,** 155–161 (1948).

Tarr, H. L. A., and Sunderland, T. A., "Drip in Unfrozen and Frozen Fillets Controlled by Brining," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **45,** 19–20 (1940).

Taylor, H. F., "Preserving Fish, Etc. for Food," U. S. Pat. 1,920,222 (1933).

Tressler, D. K., "Sanitation in a Modern Fish Filleting and Freezing Plant," *Municipal Sanitation,* **1,** 190–193 (1930).

Tressler, D. K., "Use of Ascorbic Acid in Seafood Processing Retards Rancidity and Improves Flavor," *Frosted Food Field,* **5,** No. 5, 16 (1947).

Tressler, D. K., and Evers, C. F., "The Freezing Preservation of Foods," 2nd ed., New York, Avi Publishing Co., 1947.

Tressler, D. K., and Murray, W. T., "How Brining with Pure Salt Improves Fillets," *Fishing Gazette,* **49,** No. 2, 24–26 (1932).

Young, L., "Preparation of Fish for Freezing," *Locker Operator,* **7,** No. 1, 12–13 (1945).

Young, O. C., "Cooling Curves for Fish," *Cold Storage and Produce Review,* **39,** 106–107 (1936).

Young, O. C., "Thawing of Fish I," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **47,** 3–5 (1941).

Young, O. C., "Thawing of Fish II," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **50,** 16–20 (1941).

Young, O. C., "Quality of Fresh and Frozen Fish and Facilities for Freezing, Storing and Transporting Fishery Products," *Food Technology,* **4,** 447–450 (1950).

Zarotschenzeff, W. M., "Freezing and Cold Storage in the Commercial Fisheries," *Fishing Gazette,* **65,** No. 12 (Ann. Rev.), 194–195, 202, 204, 205 (1948).

Ziemba, John V., "Speed and Quality Engineered into Fish Freezing Operation," *Food Industries,* **20,** No. 11, 77–81 (1948).

CHAPTER 17

The Principles of Fish Salting—the Salting of Cod and Other Ground Fish

The Preservative Action of Salt

Salting was used for keeping meat and fish in prehistoric times, and is thus one of the oldest methods of food preservation. However, no one knows exactly when salt was first used as a preservative for fish since the earliest records show that it was in well-established use as a preservative, both alone and in combination with smoking and drying.

Salting causes certain changes in flavor, which are undesirable to many people. Freezing, on the other hand, if carried out rapidly and at a sufficiently low temperature, has little effect on the characteristic flavor and texture of most fish. For these reasons a decreasing quantity of fish is being salted in countries which have ample refrigeration facilities. This is especially true in the United States, where fish salting is no longer of major importance, having been surpassed by both freezing and canning.

In almost all processes of fish preservation salt is used either as a condiment, or an auxiliary preservative. But, strictly speaking, "salting" is that process of preservation in which salt is the chief preservative used. In curing fish by smoking they are always more or less salted. Although lightly smoked fish are sometimes heavily salted, they are considered to be smoked because of their characteristic smoky flavor.

The principles of the preservation of fish and other products by canning in hermetically sealed cans and jars are fairly well understood by the majority of packers, undoubtedly because this process was discovered and perfected by scientists. Many canning factories employ chemists to superintend the manufacture of their products. But even among the well-educated owners of large fish-salting establishments an understanding of the chemistry and physics of fish salting seems to be totally lacking. The methods employed today in the fish-salting plants were in use hundreds of years ago and have not been modified in any important detail. The application of scientific principles to the handling and curing of meat has accomplished marvels in the meat-packing industry; but, partly because of the lack of organization and partly because of prejudice, the fish salters have not taken advantage of the discoveries of modern science. Several researches concerning the principles of fish salting have been carried out, the results of which are of tremendous value to the fish salters. These investigations show that slight changes in the present methods of salting will effect great improvements in the quality of the salted product.

Salt does not possess antiseptic properties in the ordinary sense of the word. Nearly all bacteria require some salt for their growth and most of them grow far

better in media containing 1 or 2 per cent salt than in similar media devoid of this inorganic substance. Salt preserves fish by extracting water from them. If fish are packed in a barrel of salt, the salt soon withdraws enough water from the fish to form sufficient brine to cover them. Simultaneously, with the extraction of water salt passes into the tissues of the fish and the body juices soon become a concentrated salt solution. When sufficient salt has passed in to coagulate the proteins affected by sodium chloride, and when the cells have shrunk because of the loss of a large portion of their water, the inner flesh of the fish loses much of its translucent appearance and stickiness and becomes, in the words of the salter, "struck through." The passage of salt from fish into water is an example of osmosis; the skin and cell membranes act as imperfect semipermeable membranes which permit outgo of the water and the entrance of some salt, but which prevent loss of the colloidal proteins of the cells. The flow of water through semipermeable membranes is always from the dilute to the concentrated solution. Thus, when fish are placed in concentrated brine, water passes rapidly out of the cells of the fish through the cell wall into the brine. If the fish are placed in dry salt, the moisture on the outside of the fish dissolves some of the salt and forms a concentrated solution which immediately causes the flow of water from the cells of the fish. Salt from the brine slowly finds its way through the cell walls into the protoplasm. Eventually the concentration of the solution inside the cells of the fish tissues equals that of the brine. When this condition has been reached, the salting process is complete and the fish are said to be "thoroughly struck."

Spoilage of fish is brought about chiefly by autolysis and by bacterial decomposition. In autolysis, chemical and physical changes are brought about by enzymes contained in the cells of the fish after its death. It begins almost immediately after death and proceeds most rapidly at a temperature of 98.4° F (36.9° C). The lower the temperature, the slower the action. The blood, certain tissues, and glands, such as the kidney, contain very active enzymes. The autolytic enzymes are most active under slightly acid conditions; in alkaline media their activity is greatly reduced. During *rigor mortis* the acidity of the tissues decidely increases; this change of the hydrogen ion concentration causes an acceleration of autolytic decomposition. Enzymes are most active in dilute solution and do not act in the absence of water. Most enzymes are destroyed or rendered inactive by concentrated salt solutions, therefore salting preserves fish from autolytic decomposition.

Bacteria are unicellular organisms which, when placed in suitable media, multiply rapidly and produce enzymes which break down animal tissues and the various organic substances contained in organic matter. Usually the body of the fish contains few bacteria, aside from those in the alimentary tract. However, unless great care is used in handling the fish during cleaning and washing, many bacteria are introduced into the fish. Bacteria grow rapidly at temperatures between 77–115° F (25–46.1° C). Between 30 and 50° F (− 1.1 and 10° C) most bacteria grow slowly. While many grow readily in media containing as much salt as sea water, if the amount of salt increases much above this point, the water passes out of the cell and it collapses or reverts to the spore form. Thus, strong salt solutions prevent bacterial growth.

When fish are killed, autolytic and bacterial decompositions immediately begin. At first only slight changes in the physical appearance of the fish are noted but, if the fish are not chilled, they soon develop a strong odor and taste, the blood

loses its brilliant red color, and the tissues become soft. When these changes have reached the point where odor and taste have become objectionable, the fish is said to be spoiled. The presence of more than 4 per cent of salt in the solutions in the tissues of the fish retards both autolytic and bacterial decompositions and, when the amount of salt in the solution in the fish reaches 20 per cent, the decompositions proceed so slowly that there is little danger of spoilage, except through prolonged storage at elevated temperatures. During salting autolysis and bacterial action tend towards the decomposition of the fish while the passage of the salt into the tissues and the water out into the brine, retard these processes of decomposition. If, before they become too stale, the fish are placed in brine or salt during cool weather, they "strike through" before they spoil; but if the salting takes place at such elevated temperatures that the decompositions proceed more rapidly than the salting, the fish spoil.

The Influence of the Composition of Salt

The composition of the salt used has been found by Tressler (1920) to be of great importance, not only in affecting the rate of its penetration into the tissues of the fish, but also in determining the physical qualities of the product. The chief impurities in commercial salt are calcium salts, magnesium salts, sulfates, and organic matter. Sea salts are almost universally used for the salting of fish. The composition of a number of samples collected from various parts of the world are given in Table 6 (p. 15). From these data it is seen that these salts are, for the most part, high in calcium and magnesium salts and sulfates. Turks' Island and Trapani salts, which are used in large quantities by the fish salters of the Atlantic Coast, are particularly high in magnesium salts.

Calcium and magnesium salts and all sulfates effect a retardation of the rate of penetration of sodium chloride (salt) into fish during the salting process. This retardation of the rate of salting permits more decomposition of the protein of the fish tissues during the process of salting. Therefore, it is important to use nearly pure salt when stale fish are to be salted or when the salting process takes place under adverse conditions, such as in warm climates. Calcium salts retard penetration of salt into fish to a greater extent than either magnesium salts or sulfates and are, therefore, objectionable if present in appreciable amounts. Sulfates are seldom present in sufficient quantities to be objectionable.

Calcium and magnesium salts, present as impurities in salt used for the salting of fish, affect the color and firmness of the product to a remarkable extent. Fish salted with pure salt are soft, flabby, and of a very light yellow or cream color. Such fish are easily freshened and, when cooked, closely resemble fresh fish; they possess few of the qualities commonly associated with salted fish. The presence of as small an amount as 1 per cent of calcium or magnesium in salt causes a remarkable whitening and stiffening of the flesh. Salts of both of these metals give a strong, bitter taste, characteristic of commercial salted fish. By varying the proportion of calcium chloride in common salt from 0 to 5 per cent salted fish can be prepared of any desired shade, from pale yellow to snowy, chalky whiteness. This should be of considerable value to the fish salter, for it enables him to control the color and character of his product. Salt containing as much as 2 per cent calcium as calcium chloride produces very stiff, brittle fish, quite unlike fresh fish; a like amount of magnesium chloride or sulfate produces a similar though slightly

lesser effect. Lesser degrees of stiffness and brittleness may be obtained by using salts containing smaller amounts of these impurities. Insufficient research has been done to discover the reason for the stiffening and whitening of fish by calcium and magnesium salts. Taylor (1920) has advanced the theory that the calcium coagulates the protein. Doubtless the bitter taste of fish salted with impure salt is caused by the retention of some of the calcium and magnesium by the freshened fish.

Commercial Methods of Salting Fish

There are two classes of commercial methods of salting fish in common use today: brine-salting and dry-salting. The term "dry-salted fish" refers to the method of salting and not to the procedure followed in packing or storing fish; it should not be confused with dried, salted fish.

Brine-Salting. Brine-salting is of relatively little importance commercially as compared with dry-salting. The chief fish that is salted by brine-salting is the alewife or river herring. Since the details of the salting of this fish are described in the next chapter, only the principle of the method will be considered at this point. The cleaned fish are placed in large vats, partially filled with concentrated salt solution. A small amount of salt is put on top of the fish floating in the brine. The fish are stirred daily to prevent the brine from becoming too dilute at any one point. The details of practice vary considerably in various sections but the general procedure is about as outlined above.

Dry-Salting. The exact procedure followed in dry-salting fish depends upon the kind of fish and the custom in the particular locality. But, for a general consideration of the subject the following description is sufficiently detailed: The round, gibbed, beheaded, or split fish are washed and then packed in watertight containers with an excess of dry salt. The proportion of salt to fish varies from 10 to 35 per cent of the weight of the fish, depending upon the kind of fish, the weather, and the custom of the fish salter. The fish are usually rubbed in salt just before packing and each layer is sprinkled with salt. After a few hours sufficient pickle has formed to cover the fish; they are not disturbed until completely salted, when they are either repacked in fresh pickle or removed and dried.

Comparative Efficiency of Brine-Salting and Dry-Salting. There has been much discussion of the relative value of the two methods. Tressler (1920) conducted extensive investigations concerning their merit. Using the squeteague and alewife the dry-salt method was found to obtain more rapid penetration of salt into the fish and to inhibit decomposition more quickly. Evidently, in the dry-salting process the brine remains more nearly saturated. This is probably because of the greater surplus and better distribution of the dry salt.

Influence of Methods of Cleaning

Many small fish, such as the herring and alewife, are salted round without being cleaned. Such salted fish possess distinctive flavors which are much desired by certain connoisseurs of sea food. Other small fish have their throats and stomachs cut and their intestines removed. All larger fish are always thoroughly cleaned, and are usually beheaded and split down the back. Tressler's studies (1920) concerning the rate of decomposition of fish, cleaned in various ways and salted under unfavorable conditions, clearly indicated that it is essential that all

blood and viscera be removed if decomposition is to be reduced to a minimum. The amounts of amino acid nitrogen formed during the dry-salting of alewives cleaned in various ways are presented in Table 88. Since amino acids are among the end products of protein decomposition, the rate of their formation is an excellent index of the rate of protein decomposition.

TABLE 88. DEVELOPMENT OF AMINO ACID NITROGEN IN FISH CLEANED IN VARIOUS WAYS *
(Fish Salted Four Hours after Capture, with Diamond Flake Salt Containing 99.78 Per Cent Sodium Chloride; Salting Period, Nine Days).

Method of Cleaning	Average Temperature of Salting		Amino Acid N Formed During Salting Period per Kilo of Fresh Fish	Condition of Fish at End of Period
	° F	° C	Gram	
No cleaning, salted round	79	26.1	0.77	Badly spoiled, bloated
Pipped	79	26.1	.63	Spoiled
Head cut off, abdominal cavity split open, viscera, except milt and roe, removed	79	26.1	.68	Do.
Cleaned perfectly, milt and roe removed, kidney and membranes scraped out, and all blood washed out	79	26.1	.37	Excellent condition
No cleaning, salted round	88	31.1	1.12	Badly spoiled, bloated
Pipped	88	31.1	.76	Badly spoiled
Head cut off, abdominal cavity split open, viscera, except milt and roe, removed	88	31.1	.82	Do.
Cleaned perfectly, milt and roe removed, kidney and membranes scraped out, and all blood washed out	88	31.1	.47	Excellent condition

* Source: Tressler, D. K., "Some Considerations Concerning the Salting of Fish," U. S. Bureau of Fisheries *Rept.*, **1919**, also *Doc.* **884** (1920).

Because of the tendency of the viscera, blood, and various glands to spoil round fish cannot be salted during warm weather. Scotch cured herring cannot be salted except in cool countries during the fall, winter, and spring. Fish free from blood and viscera have a milder, less "fishy" taste than round or poorly cleaned fish.

The Storage of Salted Fish

The importance of proper storage conditions for salted fish can hardly be overestimated. This is particularly true of mackerel, herring, and alewives. Under present methods of storage a very large proportion of salted fish reach the retail

dealers in poor condition. The merchant must either sell the fish immediately or keep them in refrigerators until his market demands them. Even when the retail dealer disposes of his salted fish quickly, a large percentage of them must be sold at a low price because of rust or taint.

No figures are available which show what proportion of the salted fish are culled out before they reach the consumer. A representative of one of the largest salt-fish packing establishments in this country stated that during repacking the loss of mackerel due to rusting alone varied from 10 to 25 per cent, depending upon the season. Another fish-packing house which does a mail-order business placed their loss due to rusting at 25 per cent of the mackerel business. Undoubtedly, the amount of salt mackerel culled out by the wholesale houses and retail stores because of spoilage is very large indeed.

Herring and alewives or river herring are even more difficult to keep than mackerel. Thousands of barrels of herring are dumped overboard annually because of souring and rusting. Occasionally, the entire season's output of some packing houses is discarded because of improper storage.

Cod, haddock, and other ground fish contain little fat and consequently do not rust; however, even their small fat content is sufficient to cause them to turn yellow with age and become rancid and difficult to rehydrate. When stored in boxes these fish often redden and become unfit for consumption because of bacterial growth.

The agencies causing spoilage of salted fish are those which cause spoilage of fresh fish (viz., enzymes, bacteria, oxidation, and hydrolysis). The conditions under which autolysis and bacterial growth occur have already been described. Oxidation and hydrolysis of the fat or oil of fish occur in fresh fish, but the results of their action are less easily noticed because of the slow speed at which they take place. The rate at which the various fish oils take up oxygen varies considerably. Tuna oil is one of the most active oils in this regard. Oxidation and hydrolysis of fat occur most rapidly in sunlight and in the presence of a free supply of air at high temperatures. These actions, therefore, take place chiefly on the exposed surface of the fish. The presence of sodium chloride hastens the rate of oxidation of the oils.

Because of the danger of oxidation and hydrolysis of fat and consequent rancidity fatty fish must be stored in a cool place, preferably at about 30° F (– 1.1° C) and in the absence of air if possible. On this account mackerel, herring, and alewives are usually kept under strong brines in cool storages.

While salting reduces the rate of autolysis to a slight fraction of its original speed, it does not completely stop enzyme action. The autolytic decomposition of salted flesh of fish is so slow under proper storage conditions that the fish will remain in good condition for at least 2 years. Blood and viscera rapidly decompose in salted fish if the temperature is permitted to rise above 68° F (20° C). Therefore, great care must be taken to keep cool Scotch cured herring and other round or partially cleaned salted fish.

The storage of cod, haddock, and other ground fish is a very serious problem because of reddening and the development of rancidity of the surface fat. Cool storage retards both of these actions, but in shipping small lots of fish it is difficult to keep them cool. The danger of reddening is largely obviated by "hard-drying." As this grade of cod is not liked by the domestic trade, not many fish

are so prepared, except for export trade. At least 2 different species of bacteria produce reddening of cod: One of these is a spirochete which in colonies is pale pink; the other is a bacillus whose colonies are deep red. These bacteria are particularly resistant to salt and live and grow on moist salt or strong salt solutions. Mixed colonies of these bacteria are often found varying in color from pale pink to deep red as the proportion of the two organisms present vary. The reddening organisms are found on practically all sea salts. Mined salts are free from infection with these undesirable bacteria. But as all fish-salting establishments are thoroughly infested with the organisms, a change to salts free from infection with these undesirable bacteria would not be effective in removing the difficulty unless the plants were thoroughly disinfected.

A Method of Salting Fish in Warm Climates

At one time the problem of salting fish in warm climates was a very difficult one. Many fishermen have attempted commercial salting of river herring and other fish in Florida, but were never successful until certain improvements in salting methods were discovered. Changes in the old commercial methods came as a result of careful consideration of the physical and chemical principles of fish salting and extended researches carried out at the Bureau of Fisheries, with the cooperation of Johns Hopkins University and many commercial fish-salting establishments. The solution of this problem is a matter of economic importance as it permits the cheap preservation of large quantities of fish in Florida, southern California, Brazil, and many other tropical and semitropical regions. The researches upon which the process and improved methods are based have been described by Tressler (1920) and Taylor (1921). The cardinal points of the process are outlined in the following:

After capture the fish should be carefully handled and immediately iced. All viscera and blood must be removed in cleaning. This point is most important as the blood remaining in fish will sour if the average temperature is above 68° F (20° C), whereas fresh fish free from blood can be salted at 91° F (32.8° C), or higher. After cleaning it is well to remove the last traces of blood by washing with ice water for a half hour or longer.

All large fish should be split before being salted. An ample quantity (35 pounds per 100 pounds of fish) of fine dry salt should be used in packing the fish into watertight containers. No brine should be used and the salt should be of the highest purity obtainable at a reasonable price as appreciable amounts of calcium and magnesium in common salt retard its penetration.

The fish should be rolled in salt prior to packing and a uniform quantity sprinkled over each layer. The length of time required for the salting of fish, according to previous directions, varies with the temperature and the size of the fish. Small fish such as the alewives can often be salted or "struck through" in two days.

Fish salted as described are entirely free from the strong taste of most salted fish, caused by calcium and magnesium salts retained in the freshened fish and by the slightly soured blood. Moreover, they are soft and flexible and freshen quickly, producing a fish resembling fresh fish in many ways. Salt fish, free from blood, keep much better than similar fish containing blood or entrails, and may be stored in much warmer storehouses. The temperature at which such fish

may be stored depends upon the species of fish. Mackerel may be stored at 77° F (25° C) for a month or six weeks, but herring will not remain in good condition at so high a temperature. Both of these fishes should be stored under brine. Fresh brine is preferable to that formed during the salting process.

The Salting of Cod and Other Ground Fish

The cod-salting industry is the most important salt-fish industry in the United States. In 1946 approximately 15,500,000 pounds of salted cod, valued at $1,900,000, were prepared. The centers of the industry on the Atlantic Coast are Gloucester, Massachusetts and Portland, Maine in the United States; Fortune Bay and St. Johns in Newfoundland; and Halifax, Lunenberg, and Digby in Nova Scotia. The chief cod-salting plants on the Pacific Coast are in Seattle and Anacortes, Washington; in San Francisco, California; and in Unga, Nome, Sanak, Unimak, Herendeen, Nagai, Popof, Pirate Cove, and Sand Point, Alaska.

The salting of cod was one of the earliest Massachusetts industries, as cod fishing was entirely confined to the Atlantic Coast until 1863. In that year Captain Matthew Turner caught the first fare of cod in Pacific waters off the Gulf of Tartary. Since then the number of cod caught and salted on the Pacific Coast has steadily increased, and at present the industry is of considerable importance. The growing importance of the fresh- and frozen-fish business, due to the more general use of refrigeration and cold storage, has caused a great decline in the New England salted-fish industry. Some cod are now being canned.

Methods of the New England Industry

Although some cod caught at great distances from market are salted at sea, the bulk of the catch is iced and brought to Boston or Portland; however, if there is little demand for fresh fish, they are sold to the large fish-salting firms in Gloucester or Portland. Cod are caught chiefly with haddock in otter-trawl nets. Each day's catch is partially cleaned, the entrails and gills removed, and the fish packed with cracked ice in the hold. The amount of ice used depends upon the weather and the probable duration of the trip. In winter little ice is used, but in summer large quantities must be used on the longer trips.

When the schooner arrives at the wharf, the fish are pitched into 2-bushel baskets which are hauled up out of the hold and emptied on the dock. The fish are then sorted into three sizes, large, medium, and small (snappers or scrod), and pitched into racks hanging on large scales. In all cases the pitching is done by means of short-tined pitchforks, called pews, which are similar to those used in handling hay. After weighing, the fish are pewed into carts and hauled to nearby splitting tables from which they are dumped on the floor. The cod are next pewed into racks near workmen called "headers" who break off the heads. At the other end of the tables "splitters" split open the fish and cut out about two-thirds of the backbone (that part from the head to the lower end of the abdominal cavity). The backbones and heads are thrown into barrels and are collected for glue or fertilizer manufacture. The fish are then tossed into large vats or tanks of sea water which washes them free from blood and dirt. They are allowed to remain in the vats from 5 minutes to 2 hours, depending upon the number and energy of the boys who, with small dip nets or forks, scoop the fish out of the vats and into carts and haul them to the salters.

Butt Method. In summer all of the fish must be salted in butts or other watertight containers, but in winter they are often salted in kenches. A butt is a large barrel about 3 feet in diameter and 4 feet high. The salters throw the cod face or flesh side up into the butts and sprinkle salt uniformly over each layer. When Turk's Island salt is used, 6.5 to 7 bushels of salt are required for each butt of fish. If finer salt is used, a slightly larger quantity is often added. In hot weather more salt is required. The fish are piled high above the top of the butt, and the last few layers which are exposed are placed backs up. A pile of salt is placed on top of the fish. The salt and fish settle slowly and within a day or two sink below the top of the butt. After the fish have settled a bushel or more salt is placed on top. About 3 weeks is required for the completion of the salting process.

Kench Method. In winter or at sea the cod are often salted in kenches. A kench is a regular pile of fish, made by laying them on their backs with napes and tails alternating. A considerable quantity of salt is spread over each layer and the top layer is turned back up. As the salt extracts the water from the fish, it runs to the floor and is drained off. Since the fish do not stand in brine, it is much more difficult to obtain uniform penetration of salt; therefore, there is much greater danger of spoilage (souring) by this procedure than by the butt method. About 20 pounds of salt are used on each 100 pounds of fish.

Water-Horsing. When the fish are ready to be dried, they are removed from the butts or kenches and washed with sea water or brine to remove objectionable slime. They are then hauled in two-wheeled carts to a building or room having a good concrete floor where they are kenched on frames about 8 inches above the floor. Weights of various kinds are placed on the kenches to press the surplus brine out of the cod. The fish drain and slowly dry in the kenches; the longer they remain kenched the less time must they remain on the flakes. Repiling also aids in the drying of the salted fish; but, since considerable labor is expended in this work, the cod are usually not repiled more often than is necessary to prevent spoilage. The time which the fish remain in the kenches depends chiefly upon the rate at which they dry on the flakes. If the weather is rainy and the fish already on the flakes dry slowly, those in kenches must remain there until the flakes are emptied.

Drying on Flakes. After kenching, the partially dried fish are placed flesh side up on flakes for further drying. A flake is a rack or lattice bed about 3 feet wide. It is constructed of inch-wide triangular strips nailed about 3 inches apart to a substantial framework. The flakes are built in the open air about 30 inches above a floor. Every 4 inches the fish rest on a sharp edge, thus permitting the maximum circulation of air about them. The drying yard or flake yard is often located on the roof of a building, usually that of the fish-salting establishment. Since drying under proper conditions effects a considerable bleaching of the cod, great care must be taken to produce the best quality of fish. If the sun is hot, canvas is stretched about 3 feet above the flake to shut out the direct rays which cause the fish to become yellow or "sunburned." On unusually hot days the fish are not placed on flakes. The weather is watched carefully, and when a rainstorm is imminent, the fish are collected in piles and covered with small rectangular boxes with peaked roofs called "flake boxes."

The time which the fish remain on the flakes depends chiefly upon the weather and the amount of drying and bleaching desired. When there is a strong dry

wind, 2 lots may be dried in a single day; but during bad weather a week or more may be required. The degree to which the fish are dried depends upon the trade. If they are to be sold in the southern states, they must be much drier than if they are intended for the local New England market. Fish for export must be dried as completely as possible. As flake drying is usually insufficient in the moist New England climate, such fish are dried further in specially constructed driers.

(Courtesy U. S. Fish and Wildlife Service)

FIG. 17–1. Skinning and packing dry salt codfish.

Skinning and Boning. The fish are sorted as to quality and size. The first quality cod are thick and uniformly white, with no bloodstains, and they have a "sweet" odor. If they remain long in the sorting room or if the weather is hot and humid, they are sprinkled with fine salt containing 0.4 per cent boric acid to eliminate danger from reddening. After sorting they are hauled to the "skinning loft" or to the packing rooms. If the cod are to be sold in the south or to the cheaper trade, they are heavily dusted with salt containing boric acid and tied in bundles which are packed in boxes or drums.

If the fish are to be packed for the northern retail trade, they are usually skinned, split and boned, and packed in small packages. These operations are carried out by skilled workers in a "skinning loft." The dorsal and ventral fins are removed first. The skin is pulled loose at the napes and in toward the middle of the back and then toward the tail. Care must be taken that the flesh is not torn. After the tail is cut off, the fish are turned over and the nape bones removed with a small iron gaff called a "bone hooker." The remaining portion of the backbone is then cut out and the pectoral fins cut off. Other operators then remove the larger bones with small pliers. The yellow and stained portions are cut away and the cod are cut into strips to fit the boxes being packed. Inasmuch as the large thick "middles" or "steaks" command the highest prices, the larger fish are cut so as to obtain as much of this meat as possible. These middles are usually packed in 5- or 10-pound boxes. The smaller pieces are packed in 1- and 2-pound boxes. Some salters pack their product in attractive wooden boxes lined with white parchment paper; others put the fish in a neatly lithographed carton lined with parchment paper. The white trimmings are made into "fluff" or "fibered codfish"

which is usually packed either in glass jars or in cartons with parchment paper. The cod skin is sold to fish glue manufacturers and brings an excellent price. Although the bones and yellow trimmings are also used in the manufacture of glue, they yield a smaller quantity of lower grade glue and hence are not as valuable (p. 525).

The better grades of salt cod are known as "boneless" and "not-a-bone." The former contains some of the smaller bones (the small pieces of the fins and ribs), but the latter has no bones at all. It is the practice of nearly all packers of salted cod to sprinkle the fish as it is packed with some fine salt containing 0.4 per cent of boric acid. This aids in the prevention of reddening. But even such preserved fish must be stored at low temperatures if they are to be kept for extended periods. Most packers place their product in cold storage until desired for shipment.

Hard-Dried Cod. Cod prepared especially for export trade is usually hard-dried. This grade of fish is salted in butts in the usual way. After salting, the fish are freshened somewhat by soaking in sea water, the amount of freshening depending upon the particular class of trade for which they are intended. After freshening, the fish are kenched as usual and then placed on flakes where they are left for a much longer time and become much harder than the regular salted cod. When these fish are removed from the flakes, they are placed in driers which may be large racks with chicken-wire shelves and large casters. These are run into large narrow rooms through which warm air is blown with a powerful fan. The temperature of the incoming air is kept above 70° F (21.1° C); if the weather is cool, the air is sucked through a steam radiator. The length of time which the fish remain in the drier depends on their size, on the temperature, humidity, and velocity of the air, and on the amount of moisture in the fish. No determination of the moisture content of the dried fish is made. From time to time they are examined; if they "ring" when clapped together, they are considered sufficiently dry. Hard-dried cod are sprinkled with fine salt, containing some boric acid, and packed in boxes or drums for export. Drums of regular size contain 50, 100, 200, 300, and 448 pounds of fish. When placed in drums several layers of fish are carefully arranged in circular fashion, with the flesh side up, and then a layer is placed with the backs up. The cod are well tamped with a heavy wooden tamper. Other layers are packed and the tamping is repeated. They are packed several inches above the top of the drum; a ratchet or hydraulic press is used to press them down so that the head can be put in place. Comparatively limited quantities of this grade of fish are used by the domestic trade.

Slack-Salted Cod and Pollock. Fish intended for this grade are usually eviscerated, beheaded, and cleaned on the schooner soon after being caught. They are then lightly salted and piled in kenches in the schooner. When landed at the wharf, they are usually freshened slightly in sea water and then kenched for a short time. They are then dried on the flakes. Slack-salted cod and pollock are sold chiefly in New England.

Haddock, Hake, Pollock, and Cusk. These fish are often caught with cod and other fish in the otter-trawl nets. They are landed at the same wharves, handled in the same manner, and are usually sorted as to size and species just previous to weighing. The method of curing haddock is identical with that for cod, which has been described. Hake, pollock, and cusk are salted in nearly the same manner; as their average size is much larger, their heads are chopped off. More of the back-

bone is cut out as the bones are much larger. A somewhat greater quantity of salt is used with large fish than is used with smaller cod. As the finished product is much darker than cod, especially in the case of salted pollock, it usually brings a somewhat lower price. For many purposes these fish are equal if not superior to salted cod. When cooked it is very difficult to tell them apart by the taste. These fish are often sold as "salted fish," the particular species not being indicated on the label.

Pacific Coast Industry

Statistics. The number of cod salted on the Pacific Coast of the United States increased year by year, from 7,100 in 1863 to a peak of 3,920,802 in 1914. Since that date the catch has steadily declined. In 1947, the latest year in which statistics are available, the number caught was 240,424. The following table gives the poundage and value of salted-cod products for the year 1947, as shown by statistics of the Alaska Fisheries, 1947, U. S. Fish and Wildlife Service.

TABLE 89. SALTED COD PRODUCTS IN U. S. A., 1947.

	Pounds	Value
Cod, dry-salted	769,810	$135,122
Cod, pickled	1,452	199
Cod tongues	4,664	1,632
Total	775,926	$136,953

While the methods in common use on the Pacific Coast resemble in the main those of the Atlantic Coast, there is one important difference: Practically all the cod are cleaned and salted either on ship or at shore salting stations; they are later transported to the home station where the salting process is completed and the fish are dried. The vessel-caught cod are not iced, as are those caught along the Atlantic Coast, but are salted in kenches in the hold of the ship. Those caught by the fishermen near the shore stations are lightly salted in tanks at the station, but are later carried to the home station for bleaching and drying.

The Vessel Fishery. The fish caught from large vessels along the Pacific Coast are cleaned and salted by a special "dress gang" which does little else than handle the fish. This gang consists of a "throater," "header," "splitter," "black skinner," and "idlers." The "throater" grasps the fish by the head with the left hand and by means of a short knife makes a cut on each side of the throat just behind the gills and another slit down the belly to the vent. The fish is passed to the "header" who breaks off the head at the first vertebra and tears out the viscera. The "splitter" continues the split down the belly to near the end of the tail and removes about three-fifths of the backbone, care being taken not to run the knife deeper into the fish than absolutely necessary. The "black skinner" then rubs off the membrane covering the napes and any spots of blood and drops the fish into a tub of salt water where they are washed by the "idlers."

The cleaned fish are passed through a chute into the hold where they are salted in kenches. The cod are laid on their backs with napes and tails alternating, with the exception of the top layer which is turned flesh side down. Salt is

sprinkled over each layer at the rate of 20 pounds for each 100 pounds of cod, an extra heavy portion being put on where the fish come in contact with partitions or the sides of the vessel. As the brine forms, it runs to the bottom of the hold and is pumped out.

Shore-Station Methods. The shore-stations which are located along the Alaskan coast depend upon the catch of cod on nearby banks for their fish. The fishermen row in dories from the station to the banks each morning and fish with hand lines until noon or until the boat is filled with cod. After the day's catch has been landed, the men form as many "dress gangs" as their numbers will permit and begin cleaning and salting. The fish are dressed and cleaned in much the same way as on board the schooners. The cleaned fish are hauled in large wheelbarrows to the salting house, where they are carefully placed in layers in large tanks. Salt is sprinkled uniformly over each layer. The fish are piled about 2 feet above the top of the tank to allow for settling. When they have settled below the top of the tank, enough layers of fish are added to fill it. About 17 pounds of salt are used to each 100 pounds of fish. The brine in the vats is watched closely; if it becomes weaker than 87° Sal. (87 per cent saturated), the upper layers of fish are turned backs up and bags of salt are placed on top to strengthen the pickle and press the fish down. The larger tanks in use are square and hold about 4000 medium-sized cod. The round tanks are somewhat smaller, holding about 3000 fish.

When a station vessel arrives, the pickle is drained off; the fish are then either transferred to the hold of the vessel where they are kenched or they are packed and shipped in burlap bags.

Curing at Home Station. When partially salted cod from a station or fishing vessel are landed at the home station, they are put into long troughs filled with water where they are cleaned with brushes. The fish are then placed backs down in butts in the storage houses. Some salt is sprinkled between the layers, the amount used depending upon the degree and length of previous salting. About a half bushel of salt is placed on top of the fish to strengthen the dilute brine which may come to the surface. The salted fish remain under cover in the butts until an order is given to remove them. They are then water-horsed and dried on the flakes. The procedure followed is the same as that already described as being in use in New England. The dried cod are then skinned, boned, cut up, and packed in packages in nearly the same way as on the Atlantic Coast.

Salted Cod Tongues. Cod tongues are saved whenever possible. On the vessel one of the "dress gang" usually cuts them out, while at the stations someone other than a regular fisherman usually does this work. A cod's tongue is attached to the lower jaw, and when cut out includes all that part of the jaw lying inside the jaw bone. The operator, using the eyes for finger holds, takes hold of the fish by the back of the head. As he lifts the fish, its mouth usually falls open; with his other hand he cuts the tongue loose on the sides with a sharp knife, then cuts loose the lower end along the curving bone forming the back part of the lower jaw. The tongue is then hanging by a thin strip at the forward end of the jaw, from whence it is torn loose by the hand. The tongues are cured loose in barrels with salt. When they are thoroughly "stuck," they are packed in barrels holding 200 pounds. The barrels are headed up and a strong brine is added through the bung. They are sold in these barrels or else repacked in half-barrels, pails, and kits. Cod tongues, when thoroughly freshened, rolled in cracker crumbs, and fried,

are considered a delicacy by many connoisseurs. Salted cod tongues cannot be kept much over a year as they gradually harden.

Barreled Salted Cod. There is a small trade on both coasts in salted cod packed in brine. A few haddock are also sold in brine on the Atlantic Coast, but hake, pollock, and cusk are seldom marketed in this condition. For this trade the fish are dressed, split, washed, and salted in butts in the same manner as those prepared for drying on the flakes. When orders are received, thoroughly salted fish are removed from the butts, cleaned with brushes, and packed flesh side up in tight barrels or half barrels, the fish being bent to follow the curve of the barrel. Salt is placed on the bottom of the barrel and over each layer of fish, about 1 peck of salt being used to each barrel of fish. After heading the barrel, strong brine is added through the bung.

REFERENCES

Ackerman, E. A., "New England's Fishing Industry," Chicago, Univ. Chicago Press, 1941.

Anon., "New Codfish Curing Plants in Spain," U. S. Dept. of Commerce, *Foreign Commerce Weekly*, 33, No. 9, 25–26 (1948).

Cobb, J. N., "Pacific Cod Fisheries," U. S. Bureau of Fisheries *Doc.*, **1014** (1927).

Dyer, W. J., "Yellow Stains in Salt Fish," Fisheries Research Board of Canada, *Prog. Repts., Atlantic Coast Stations*, **45**, 14–15 (1949).

Gerhardsen, G. M., and Gertenbach, L. P. D., "Salted Cod and Related Species," Food and Agriculture Organization, *United Nations Fisheries Study*, **1** (1949).

Innis, H. A., "The Cod Fisheries—History of an International Economy," New Haven, Yale Univ. Press, 1940.

Jackson, R., "Newfoundland—the Salt Cod Industry," *Canadian Fisherman*, **35**, No. 11, 12–15 (1948).

Jarvis, N. D., "Curing of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.* **18** (1950).

Lovern, J. A., "The Fishery Industries of North America. Part 2. Salt Cod," *Food Manufacture*, **23**, 206–209 (1948).

Taylor, H. F., "Principles Involved in the Preservation of Fish by Salt," *Am. Fisheries Soc. Trans.*, **1920**, 120–152.

Taylor, H. F., "Improvements in Process of Salting River Herring Especially Adapted to Warm Climates," U. S. Bureau of Fisheries *Doc.*, **903** (1921).

Taylor, H. F., "Principles Involved in the Preservation of Fish by Salt," U. S. Bureau of Fisheries *Doc.*, **919** (1922).

Tressler, D. K., "Some Considerations Concerning the Salting of Fish," U. S. Bureau of Fisheries *Doc.*, **884** (1920).

Tressler, D. K., "Chemical Problems of the Fishery Industries," *Hexagon Alpha Chi Sigma*, **17**, 55–67 (1927).

CHAPTER 18

Salting of Other Fish

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Introduction

With the steadily increasing production of fresh, frozen, and canned fish products during the last half century, there has been a corresponding decrease in the production and use of salted fish items in the United States. In 1904 the total pack of salted fish was 113,576,290 pounds, while the last available figures, which are for the year 1945, indicate that this amount is now less than half: 50,907,304 pounds. This shifting of the demand is undoubtedly due to a number of factors, such as the improved techniques in processing, packaging, and transportation; the greater ease of consumer preparation; and better flavor of the fresh, frozen, and canned articles. Even in European countries, where salt fish has long been a staple article of diet, this same trend is manifesting itself, although not so pronounced as in this country.

The fish-salting industries are located chiefly in Northern Europe, Canada, Newfoundland, the United States, Japan, and Siberia. The location of these industries in these countries depends largely on climatic conditions and the abundance of fish. Warm countries, such as those of Southern Europe and Brazil, are not well suited for fish salting as such great care must be exercised in all operations if a good product is to be obtained. In Japan, where meat is scarce and expensive and fish one of the chief articles of diet, all surplus fish are carefully preserved; large quantities are conserved by salting as it is one of the cheapest means of fish preservation. In rugged northern countries with long coast lines, such as Scotland and Norway, where farming is attended by many difficulties and is insufficient to support a large population, fishing is one of the principal industries. Since the climatic conditions are ideal for the preservation of fish by salting, the industry has been established in these countries for centuries.

Cod and other ground fish are usually salted, allowed to develop their own brine and, after being thoroughly struck, are dried in the open air and stored in a

dry condition. These processes have been described in some detail in the preceding chapter. As ground fish contain very little fat, the salted fish may be stored dry. But since fish oil oxidizes and hydrolyzes, quickly becoming rancid and causing rusting of the fish, salted fatty fish, such as herring, alewives, mackerel, salmon, and shad, cannot be dried or stored where they are exposed to air.

In the methods of salting, which are described in this chapter, the fish are kept under brine or away from the air at all times. Herring, salmon, and mackerel are always salted in watertight containers and are under pickle as soon as the salt extracts sufficient water to form enough brine to cover them. When repacked for market, they are placed in watertight kegs or barrels which are subsequently filled with brine. Alewives are either salted in the same manner or placed in vats of brine. When packed for market, they are arranged compactly in tight barrels so as to exclude as much air as possible.

Since the general physical and chemical principles of fish salting have been described in the preceding chapter, further theoretical consideration of the salting of fatty fish is unnecessary. Statistics showing the quantity and value of all species of fish salted in the United States in 1945 are given in Table 90 (Anderson and Powers, 1949).

TABLE 90. QUANTITY AND VALUE OF SALTED FISH PRODUCED IN THE UNITED STATES IN 1945.

Item	Quantity in Pounds	Value
Alewives (River herring)	7,094,950	$ 164,981
Cod	15,337,266	1,847,204
Cusk	32,215	4,355
Eels	122,620	10,551
Haddock	76,115	7,143
Hake	2,255,525	122,377
Herring, lake	5,036,574	158,988
Herring, sea	2,429,485	287,794
Hogchoker	3,000	140
Lake trout	27,000	2,100
Mackerel	3,573,448	269,268
Mullet	1,830,800	134,565
Paddlefish (Spoonbill cat)	1,595	812
Pollock	451,207	17,844
Sablefish (Blackcod)	180,290	10,002
Salmon	11,489,327	2,489,718
Spot	385,400	23,890
Unclassified *	580,487	40,718
	50,907,304	$5,592,450

Source: Anderson, A. W., and Powers, E. A., "Fishery Statistics of the United States for 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, 18 (1949).

* Includes dry-salted barracuda, dry-salted bonito, salted blue runner, whole salted hake, salted jewfish fillets, salted menhaden roe, dry-salted pilchard, salted salmon bellies, dry-salted sea bass, salted sea trout, salted sturgeon roe, salted tuna fillets, salted yellowtail tuna, and salted tongues and sounds.

Salting of Salmon

In actual poundage produced the salt-cod industry still ranks as No. 1 in the salt-fish industries of the United States, but running a close second in volume and considerably ahead in value is that of salted salmon. While it is true that the production of hard-salted salmon has decreased tremendously, the pack of mild-cured salmon still continues at a fair volume and will probably show some increase if the European market should once more become available. The preparation of mild-cured salmon is confined to the Pacific Coast region, with some production in all three of the coastal states, as well as in Alaska and British Columbia.

Mild-Cured Salmon. This lightly salted product may be considered an intermediate or half-finished one, since the major portion is subsequently used in preparing smoked salmon. An unsuccessful attempt in salting a shipment for the German market in 1889 marked the introduction of this method of curing to the Pacific Coast. Volume production was not reached until the establishment of two plants on the Columbia River in 1898. Puget Sound mild-curing began in 1901, and by 1906 packing of this product in Alaska was well under way. Present production runs from 10 to 15,000 tierces annually, with each tierce containing 825 pounds net weight.

Large king salmon of the red fleshed variety are used almost exclusively for mild-curing purposes, although at times a few tierces of white king, silver, and chum salmon may be prepared. In the case of king salmon only those weighing over 14 pounds dressed are used for curing. The quality requirements of salmon used for mild-curing are extremely rigid: the fish must be (1) absolutely fresh; (2) in a fat condition; (3) of bright color with no watermarks; (4) free from signs of rough handling, such as bruises and pew marks; and (5) free of belly burn. Troll-caught ocean fish are ordinarily the only fish meeting these requirements. Since these are feeding when caught, the usual practice is to gut them immediately upon catching, with the head being retained. They are next iced well in the fish hold. Extreme care is exercised in all subsequent handling and the fish are held in ice at all times until ready for the curing process, which should start as soon as possible after arrival at the plant.

Butchering. In removing the head an effort is made to leave as much of the bony structure above and below the collarbone as possible. This not only adds to the weight of each side, but allows for easier handling in splitting, sliming, salting and smoking. The fish are then scored on both sides by making a series of shallow incisions with a small knife, just deep enough to penetrate the fatty tissue immediately under the skin. Each score is 1 to 1½ inches long, with 4 to 6 scores in each row; 3 to 4 rows, running lengthwise, are made on each side, depending on the size of the fish. This scoring allows for faster and more uniform salt penetration.

Splitting. This important operation should be performed by an experienced man in order to avoid excessive loss, due to too much flesh being left on the backbones. The fish is placed on its side with the belly toward the splitter. The nape, which is to the right, is hooked over a short nail protruding from the table, so as to hold the fish securely. Two preliminary cuts, called undercutting, are made in the fleshy part just back of the body cavity. Cut No. 1 is made from the vent back-

ward toward the tail passing under the anal fin, and also over the backbone. The depth of this cut should only be sufficient to expose the vertebrae. The second cut is made parallel to the first, just under the backbone and of the same depth. Without these two preliminary cuts it would be impossible to make a clean flesh-free removal of the backbone. The splitting operation is done with a long, specially shaped knife, the end of the blade of which is nearly square. The knife, which is held in the right hand, is entered at the nape just above the backbone. The left hand is then placed on the knife to assist in making the cut and at the same time holding the belly wall out of the path of the knife, so that it is possible to cut closer to the backbone. With the knife held at a slight downward angle the upper half or side is removed with one stroke. The dorsal fin remains with the under half. The backbone is now removed by inserting the knife at the nape under the bone. When the knife is held in the right hand and the blade at a slight upward angle, one stroke from nape to tail removes the backbone with the attached tail fin. An expert splitter will cut so close that a small portion of each vertebra is cut off, leaving a white line down the middle of each side and leaving a minimum of flesh along the backbone. None of the fins are removed in the butchering or splitting.

Sliming. This is a term applied by mild-curers to the washing and cleaning of the sides. Immediately after splitting each side is placed in a shallow tank of cold water. The "slimers," who work on a board along the edges of the tank, scrape off the slime on the skin, remove all loose ends of membranes, press the blood out of the veins, and wash the sides. In this, as in all other operations, the sides are carefully handled so as to avoid bruises, cuts, or tears.

After sliming some packers make a practice of chilling the sides by placing them for an hour or two in a tank of 60–70° Sal. brine, held at a temperature of 40° F (4.4° C) or less. This produces a certain amount of "case hardening," which slows down salt penetration; some believe that too rapid penetration at the start is not desirable. Chilling also tends to draw out any excess blood and reduces oil loss. In warm weather this chilling operation is undoubtedly advisable, but in cooler weather it is usually not practiced.

Salting and Packing. After sufficient draining the sides are taken one at a time and laid skin down in a box filled with special "mild-cure" salt. This is a fine, even-grain salt of high purity, manufactured especially for this purpose. The upper or cut surface of each side is covered completely with salt by gently scooping it by hand rather than by rubbing it. As each side is lifted from the salt box, all loose salt is allowed to fall back into the box. Thus only the thin layer of salt, which adheres to the sides, goes into the tierces, plus the additional loose salt sprinkled over each layer.

The fish are packed in large barrels known as tierces, which when filled hold approximately 825 pounds of fish. A few handfuls of salt are thrown over the bottom before placing the first layer of sides. All layers are packed with the skin down except the top one, which is reversed. The sides are laid flat, alternating tail and nape, with the backs of the first two sides close to opposite sides of the tierce. The remaining sides are then filled in toward the middle. In placing the sides there should be a slight overlapping with the back or thicker part of one over the belly or thinner part of the next. Each layer should be level and solid when complete. A few handfuls of salt are scattered over each layer, the amount

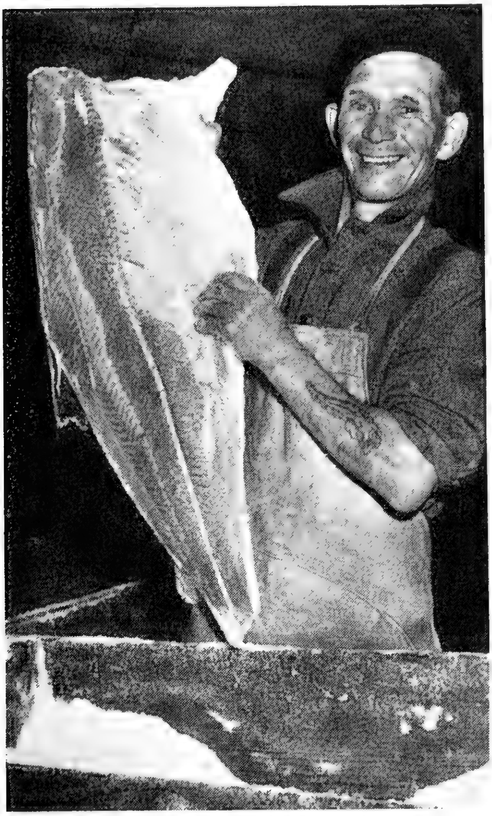

FIG. 18–1. Side of salmon as it is being salted away in tierces in fish house at Ketchikan.

(*Courtesy U. S. Fish and Wildlife Service*)

(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 18–2. Salmon packed in tierce in fish house at Ketchikan.

depending on the size and fatness of the fish. A total of 80 to 100 pounds of salt are used per tierce.

Heading and Storage. At this stage some packers prefer to let the tierce stand for 24 hours, by which time the contents will have settled so that a few more sides can be added. The tierce is then headed and filled with 100° Sal. brine; however, the usual practice is to head and brine immediately after packing. The brine used should be made from pure water with salt of the same high purity as that used for packing. This brine is often strained through cheesecloth in order to separate foreign material. After heading and filling the tierces are rolled into a cool room. Here they are held at a temperature of 35 to 40° F (1.7 to 4.4° C) for curing and until time for repacking. Storage temperatures should be held uniform as fluctuations tend to cause loss of oil from the fish. It is also important to keep the tierces full of pickle at all times during curing and storage. There may be loss of brine due to leakage and to absorption of the brine by the dry wood of the staves. If the tierces are not kept filled, there may be shifting of the sides in handling the barrels, which may result in some of the sides becoming broken. Loss of brine will leave some of the fish exposed to the air. The "rust" spots that develop at these points will also lower the quality.

There is considerable shrinkage or loss of weight during the first 10 days of curing, the amount depending on the fatness of the fish. Extra fat fish may lose as little as 10 per cent, while lean ones may shrink up to 35 per cent. However, after this original loss the sides begin to absorb brine and take on weight so that after several months' storage most of the fish will have returned to their original weight.

Repacking. Because of this early loss of weight it is advisable not to repack too soon after packing; hence, 20 days is usually considered the minimum for curing. When ready for repacking a number of tierces are rolled into the repack room, and the heads of the tierces are removed. The sides are then taken out one by one and carefully selected as to grade, after which the fish are placed in the proper grading bin. Grading is done according to size, color, and quality. The size is designated by the number of sides per tierce (viz., 50–60, 60–80, 80–100, and 100–120). Three colors, red, pale, and white, are usually recognized, but gradations between these are sometimes used. Quality is generally based on the fatness of the fish; they are marked prime, thin (T), and double thin (T.T.). Repackers must also sort out the broken sides, which are marked B; the badly broken sides are labeled B.B.; 825 pounds of one grade only are repacked in each tierce. The sides are laid exactly as in the original packing, but no salt is added. After heading the tierces are filled with 100° Sal. brine. After stenciling the number of sides and the color and quality on the head, the tierces are returned to the cool room to await shipment. Repacked tierces must be inspected from time to time for loss of brine and must also be refilled when necessary. It is advisable to make all shipments under refrigeration.

Mild-cured salmon may be smoked any time after repacking or may be held in storage for extended periods; however, sides held over a year are more difficult to freshen and never take on as nice an appearance during smoking as newer stock.

Hard-Salted Salmon. The first commercial utilization of Pacific salmon was by means of hard-salting in barrels. In the early years this was a sizable industry and after several years the pack was over 10,000,000 pounds. Recently the amount

(140,000 pounds in 1944) has declined, and at present practically all production is confined to Alaska. The major market is in the Hawaiian Islands although a considerable quantity is smoked and sliced for tavern trade.

All species of salmon may be used in preparing this product, but red salmon is regarded as yielding the best quality. Of late a larger amount of silver salmon, producing an excellent pack, has been utilized. Only strictly fresh fish of high

(Courtesy U. S. Fish and Wildlife Service)

FIG. 18–3. Salmon tierces with funnels in place, in fish house at Ketchikan.

quality should be used. Belly-burning or pew marks are cause for rejection, and salmon approaching the spawning period are not satisfactory because of lack of fat, color in the flesh, and excessive slime and watermarking on the skin.

Butchering and Splitting. Salmon to be prepared by hard-salting are generally received in the round from the fishermen. After a preliminary washing the fish are beheaded in the usual manner; then without gutting they are split along the back, leaving the belly intact. The front two-thirds of the backbone are also removed, as well as the viscera, blood, and membranes. This is followed by a thorough cleaning and scrubbing in fresh clean water. In the case of large king salmon it is customary to split the fish in two sides, somewhat similar to the operation used in mild-curing.

Salting. After proper draining the fish are ready for salting in tierces or large tanks or vats, either square or round, some of which may be of 100-barrel capacity. A thin sprinkling of salt (usually half-ground) is scattered over the bottom. A layer of fish is then placed with the skin side down. In laying the fish no special method is followed, except that each layer should be as level as possible. Salt is then spread evenly over the flesh surfaces, approximately 25 pounds of salt

used for each 100 pounds of salmon. This process is continued until the fish are several inches above the top of the tank, with the top layer having the skin up. As the salt extracts moisture, the fish will settle in the tank and eventually become covered with brine if some weight is placed on top. By keeping the fish immersed in brine an even cure will result and danger of "rusting" will be eliminated. The fish should cure in their own brine for 10 to 14 days before repacking.

Repacking. After removal from the curing tanks the fish are washed and scrubbed in a weak brine to remove any accumulated salt, slime, and blood. They are first graded as to species and then for quality. The No. 1 grade of any particular species must be only choice freshly caught fish of good flesh and skin color, without discolorations, pew marks, or blood-clots. Any fish with a blemish of any kind should go into the No. 2 grade. Repacking is done in barrels holding 200 pounds net weight, with the skin side down except for the top tier. A handful of salt is placed on the top and bottom of each barrel, with a light sprinkling between layers. If the fish have cured a minimum of 14 days, 10 pounds of salt should suffice for the repacking. The barrels are then headed and filled with 100° Sal. brine. The species, grade, and weight should be stenciled on the top of each barrel. Since this product is hard-cured, refrigerated storage is only required in warm weather or for shipment and storage in the warmer latitudes, such as in the Hawaiian Islands, which is one of the principal markets.

The Salting of Herring

Largely because of economic reasons, as well as a lessening demand, the salting of herring in America has become an industry of minor importance. However, on a world-wide basis the herring is still the most important cured fish. It is preserved by salt in more forms and by more methods than any other species of fish. The grades and names of the different products are determined by the size and fatness of the fish, the method of cutting and packing, the quantity of salt added, the amount of blood and viscera remaining in the flesh during the curing process, and the quantity of milt and roe in the fish. The production of salt herring constitutes a major industry in Iceland and Northern Ireland and those countries bordering the North Sea: Norway, Scotland, Holland, England, Sweden, Germany and Denmark. In the Western world salt herring is packed in Newfoundland, Nova Scotia, British Columbia, Alaska, and in some of the New England states.

As previously stated there are many variations in the details of the curing methods, but in general these may be classified as: (1) Round cure; (2) Split cure; (3) Scotch cure; (4) Dutch cure; and (5) Norwegian cure.

Round Cure. In this method the fresh herring are usually washed to remove loose scales, blood, and slime. Then without any butchering or further cleaning the fish are salted into large barrels or vats, using 30 to 40 pounds of salt per 100 pounds of fish. No effort is made to place the fish in any particular pattern. A weighted cover is placed on top of the filled container; if sufficient brine has not formed by the second day, enough fresh brine of 100° Sal. should be added to completely immerse the fish. About 10 days is required for complete curing, during which time the fish may be stirred occasionally to prevent massing. If the salt and herring have been properly mixed, this stirring should not be necessary.

When thoroughly "struck" the herring are removed from the vats and repacked in barrels, usually of 200 pounds net weight, although at times other sizes may be

used. In the repack the fish are usually arranged in layers or tiers, with the backs down and on a slight slant. Each layer receives a sprinkling of salt, about 20 pounds being used per barrel. The barrels are then headed and filled with fresh 100° Sal. brine. Small quantities of the salted round herring are purchased by the ultimate consumer, but most of it is sold to the smokers for manufacture into smoked bloaters.

A variation of this cure is the so-called dry-salted or Oriental cure as practiced on the Pacific Coast, especially in British Columbia, for shipment to the Orient, especially China, where salt is at a premium. The fish are cured round in large tanks or vats exactly as previously described. However, after being thoroughly cured the herring are shoveled out of the tanks onto the floor, where they are allowed to drain for 1 to 2 days. All excess salt from the curing tanks is spread on top during this draining period. The herring are next shoveled into large wooden boxes holding from 425 to 450 pounds, with the salt being mixed in as the boxes are filled. If the supply of excess used salt is meager, some additional new salt must be added. After the covers are nailed on, the boxes are ready for shipment. This same method of curing and repacking has been employed for salting large herring, which are later prepared as smoked bloaters.

Split Cure. Although this method is not important from the standpoint of volume, it has been used for large herring in New England and eastern Canada. The fish are first washed in brine to set the scales and to facilitate handling. The bellies are split down to the vent and the gills and viscera removed. The milt and roe are usually taken out also. After cleaning, the fish are soaked in a light brine or clean salt water for 2 or 3 hours to remove the blood and slime. They are next drained and then packed in large barrels or vats. In packing the fish are laid with the belly cavities up, which are filled with salt. In addition some salt is scattered over each layer, with a total of about 35 pounds of salt for each 100 pounds of cleaned herring. Split herring cure in about 7 days, after which they are ready for repacking in barrels of 200-pound capacity. In the repack the fish are laid straight on their backs, with each succeeding layer crosswise to the one below and with a very light sprinkling of salt over each layer. The barrels are then headed and filled with full strength brine.

Scotch Cure. The chief consumer markets for salt herring in the United States have always been in the large cities of the east and midwest, with their large foreign population centers. This demand, especially with the Jewish trade, has always been predominantly for salted herring cured by this method, which, of course, originated and developed in Scotland. In fact before World War I imports from Scotland supplied the entire market for this type of salt herring, which was around 200,000 barrels per year at that time. The effectiveness of the German submarines during that war halted the importation of all salted herring from Europe, thus forcing New York and other consuming centers to look elsewhere for supplies. Several districts in North America, among them Newfoundland, British Columbia, and Alaska, began to supply the demand. The U. S. Bureau of Fisheries sent instructors to Alaska to assist in the introduction and development of the Scotch cure in that area. The results were remarkable as evidenced by these pack figures: 1915–8,691 barrels; 1916–18,296 barrels; 1917–23,557 barrels; and 1918–105,394 barrels. There was a temporary slump for a few years, followed by a peak of 145,325 barrels in 1922 and 139,157 barrels in 1925. Since that

time the Alaska production has declined greatly, so that at present the annual production is only from 2,000 to 10,000 barrels. Herring packers in Iceland and Norway have also adopted the Scotch method of curing. Alaska producers have found it extremely difficult to continue in competition with imports now coming from the various European countries. The method of Scotch curing as adapted for Alaska will be described and will differ only in very minor details from that practiced in Europe.

To be suitable for this cure the herring must be strictly fresh and free from feed, and processing should start immediately upon arrival at the plant. The fish are not washed before handling nor at any other time previous to the refilling.

Gibbing and Grading. Gibbing or gutting is done with a small knife, by means of which the gills and most of the viscera are removed along with the pectoral fins. The milt and roe are, however, never pulled out in the gibbing process. This work is generally done by women, who stand facing the hopper in which the fresh herring are stored and from which they are dropped onto a shelf or table immediately in front of the gibber. A small hole in the table top allows for disposal of refuse. Directly behind the "gibber" are two or three bins into which are dropped the several sizes or grades of herring. Although 4 sizes are recognized, the herring are seldom of such mixed sizes that 4 bins are required. In fact most of the time two bins are sufficient. The grading is based on the sexual maturity and the length of the fish as follows:

SIZE (fresh)	FULL FISH (with milt and roe)	EMPTY FAT FISH (Matjes)	COUNT PER 250 POUND BARREL
Over 12½ inches	Extra Large Full	Extra Large	350– 450
" 11½ "	Large Full	Large	500– 600
" 10½ "	Full	Medium	650– 750
" 9½ "	Matful	Select	800–1000

Since herring shrink about ¼ inch during the curing process, an allowance of this amount should be made when measuring salted herring.

As a general rule herring caught after October 1 show sufficient milt and roe at the throat opening so they can be called full fish. Those cured before that date are empty fat fish and are usually given the "matje cure." This is essentially the same as the regular Scotch cure, except that slightly less salt is used on the tiers and the pack is a little looser in the barrel.

Rousing and Packing. The bins generally hold an even half barrel of fish; as soon as one is filled, the herring are thoroughly stirred and mixed with salt. For this operation, which is known as "rousing," a special kiln-dried "rousing" salt is used. This is fine grained and dry so that it will stick and cover each fish thoroughly. Thorough rousing is highly important in securing an even cure.

Packing, which should be started immediately after rousing, is done in whole barrels of 250-pound capacity or in half barrels holding 125 pounds of fish. The outside of the bottom of the barrel should be marked to indicate grade, date, and packer, which information is necessary when refilling. No salt is placed on the bottom of the barrel since sufficient salt adheres to the fish in the rousing process. The herring are carefully laid in tiers, straight on their backs and as close together as possible. The first fish is placed along one side of the barrel at right angles to the grain of the wood. The next two are laid against the first one with their heads

to the side of the barrel. A middle herring is then placed against these two and the laying is continued across the bottom in this same manner. Each fish must be kept as straight as possible and care taken that they are not on a slant or in irregular rows. The spaces at the sides of the barrel where the heads meet are filled with 2 or 3 herring, which are known as "head herring." This makes a smooth even surface for the next tier, which is laid at right angles to the first. Each successive layer is at right angles and a light sprinkling of salt is placed on each tier. The amount of salt used depends upon the size and condition of the fish. Large herring require more salt than small ones and full herring more than empty ones. The quantity of salt over each tier should be increased slightly from the bottom to the center of the barrel and decreased from center to top.

When packing empty fat herring (matjes) it is advisable to head the barrel at once, lay it on the bilge (side), and fill it with 100° Sal. brine. At other times the barrels can stand until the following day, by which time they will have settled enough so that another tier or two of fish can be added. They are then headed and filled with brine. In curing, the barrels should always be stored on their sides or bilges and, if convenient, given a half roll from time to time. This will ensure a more uniform cure. While in this preliminary curing stage the herring are said to be "in seastick." The seastick period will vary from 10 to 14 days for regular cure, but matjes are generally held a shorter time before refilling.

Refilling. In this operation the barrels are stood on end, the heads removed, and a bunghole bored in one of the wide staves near the center of the barrel. The brine draining from the upper half of the barrel is caught in a pail and poured

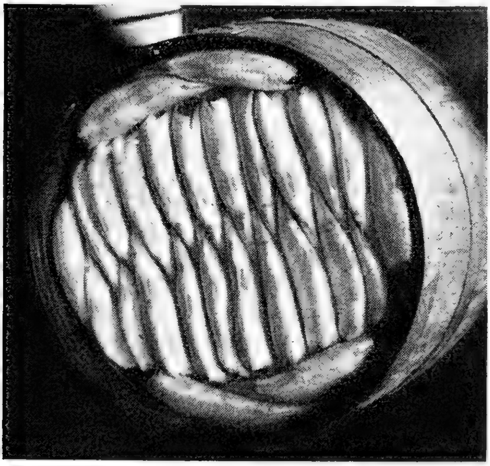

Fig. 18–4. Repacked Scotch-cured herring.

(Courtesy Pacific Fisherman)

over the top of the barrel to wash down loose scales and any free salt present. This is repeated 2 or 3 times, but the brine is never drained below the bunghole. At the time of refilling this original brine should test 80–85° Sal. for matje cure and with no free salt between tiers. Regular cure brine should test 95–100° Sal. and a little free salt is permissible.

This process results in some settling so that several more tiers of fish are required. For this purpose only fish of the same day's pack and grade should be used. Before

being used for refilling the herring are washed in brine to remove loose scales, salt, etc. The refill packing is done in the same manner as the original, but no salt is added and special care is taken in laying the top tier. A nice appearing top with a smooth surface without holes or openings has a very attractive sales appeal, when the barrels are opened later for inspection. The barrels are again headed and filled with 100° Sal. brine. The heads are then stenciled with the packers name, station, grade, etc. Shipment should be made as soon as possible, so the product can be placed in cold storage to prevent spoilage. This is especially important for the mild salted matje type herring.

Dutch Cure. Herring fishing and curing has been one of Holland's principal industries for hundreds of years. Holland herring have had a good reputation for quality, and perhaps this may be due in no small measure to the fact that the fish are gutted and salted by the fishermen immediately after catching. It is only during glut periods and when the fishing is close to shore that packing is done on land. Since the fish are caught in gill nets, there is more uniformity of size, with usually only 1 or 2 grades based on length. During July, August, and part of September only fat empty fish of superior quality are caught. This, the best grade, is called the Northern cure and may be marked M for "Maatjis." The Sand or Dogger cure and the Southern cure are comprised of full herring with milt and roe, and may be branded "VOL." The poorest quality is the "Spents," which have just spawned and which are suitable only for pickling in vinegar.

In preparing the herring the fisherman gib or gut them, in somewhat the same manner as in the Scotch cure, by using a small knife to remove the gills, entrails, and pectoral fins. As in the Scotch cure the fish are not washed. After gibbing the herring are rolled or dredged in fine salt previous to packing in barrels. Packing is done in tiers with the fish laid straight and on their backs. Each succeeding tier is at right angles to the one below and a light sprinkling of salt is placed on each tier. When filled the barrels are headed, brined, and lowered into the hold of the vessel for curing. After curing 6 to 10 days the barrels are opened and some of the brine is drained off and refilled. This refilling is essential to prevent movement of the herring within the barrels, which would cause the rubbing of skin and loss of scales whenever the ship rolled during transit. The final refilling or repacking is done ashore. Although the 100-kilo (220-pound) barrel is the standard container, much of the Holland herring is marketed in small kegs of 9 pounds net weight. These small containers, packed with milt herring only, are a favorite with certain classes of trade because of their excellence for pickling in vinegar and spices.

Norwegian Cure. This method of curing is essentially a harder cure than either the Scotch or Dutch, and probably because of this less care is used in the gibbing and packing. The fat summer herring are held in pounds several days to free the entrails of feed, while the winter and spring fish are non-feeding. Since there is less danger of enzymic spoilage, complete gutting is not necessary. The gibbing is done with a special scissors, which cuts a triangular piece from the throat removing the heart and pectoral fins, but not the gills. This cut is deep enough to sever the blood vessels close to the backbone, thus allowing for free bleeding. Although a few packers wash the herring at this point, washing is not the customary practice. The gibbers grade the fish as follows:

Trade term	Length	Number per 220 lb. bbl. (100 kilos)
KKKKK	Over 12 inches	350–400
KKKK	11 to 12 inches	425–475
KKK	10 " 11 "	525–600
KK	9 " 10 "	700–800
K	8½ " 9 "	800–900

The standard barrel used is one of 100-kilos (220-pounds) capacity. The herring are packed directly in the barrels without any preliminary rousing or dredging. A sprinkling of salt is placed on the bottom of the barrel, then a tier of herring with their backs down and slightly slanted. Packing is fairly loose. After covering with salt, a second tier is laid at right angles to the first. This is continued until the barrel is filled. About 70 pounds of salt are used per barrel. At this stage the barrels may be headed and filled with 100° Sal. brine, or allowed to stand for a day or two to permit settling. In the second case another two or three tiers of fish can be added before heading and brining. Eight to 10 days are allowed for curing, after which time the barrels are reopened and refilled to take care of shrinkage. Ordinarily in refilling it takes 1 barrel to refill 4 of the finished. Heading, brining, stenciling the grade, etc. completes the process.

In Norway a combination of the round cure with "after-gibbing" is often used in salting the winter and spring herring. At times these herring are caught in such tremendous quantities that it is impossible, because of insufficient help and space, to gib and pack the fish in barrels upon arrival at the plant. As a time and space saver the herring are salted in the round condition in large vats or tanks. Many of these are constructed of concrete and will hold from 1,500 to 2,000 barrels of herring. A number of plants have a total curing capacity of from 30,000 to 40,000 barrels. After the herring are sufficiently cured and the rush is over, they are removed from the tanks for further processing. The gibbing is done with scissors, as previously described, after which the fish are graded for size in separate bins or tubs; 100 kilos (220 pounds) are weighed and packed in each barrel in the usual manner. This is followed by the customary heading, brining, and stenciling or branding.

The Salting of Alewives

Alewives or river herring are caught and cured along the entire eastern seaboard of the United States from Maine to Florida, but the salting industry is centered in Maine, Massachusetts, Maryland, Virginia, and North Carolina. These fish, which closely resemble the sea herring in appearance, are anadromous in their habits and run up the coastal streams in the spring to spawn. The run extends from January to March in Florida and gets progressively later to the north, showing in the rivers of Maine and Massachusetts in June and July.

Corned Alewives. Of the total production of salted alewives 7,094,950 pounds in 1945, by far the major portion, 5,914,250 pounds, were "corned" or lightly salted for prompt shipment to the trade. In Virginia and North Carolina large amounts of river herring are cured and marketed for immediate consumption early in the season while the weather is cool.

Upon arrival at the packing plants the fish are cleaned by cutting off the head, splitting the belly, and removing all the entrails. This work is usually done by

women using a small sharp knife. The gutted fish are washed thoroughly in large tanks of running water to remove the blood, slime, and loose scales. After draining to remove the excess water the fish are dumped into salting vats, which have been previously filled about one-sixth full with 100° Sal. brine. As the fish are being dumped into the vats, a quantity of salt is spread over them. The time of cure is only from 12 to 48 hours, depending upon the temperature and the distance which the corned fish are to be shipped. After brining the fish are taken from the vats, spread on the floor, and mixed thoroughly with salt, after which they are packed in barrels without brine and immediately shipped to the trade. Corned fish can be safely handled only when the temperature is below 60° F (15.6° C).

Round Cure. In 1945 about 900,000 pounds of alewives were salted round or in ungutted condition. After a preliminary washing the fish are heavily salted in large vats or directly in barrels. In the latter they are tightly packed in tiers, with a covering of salt over each tier. No brine is added, but a sufficient amount forms from the water extracted from the fish by the salt. When ready for marketing the salted alewives are repacked in barrels, headed, and filled with brine.

Tight Pack or Hard Cure. The balance of the salted alewife pack is cured by this method. The first part of the process is exactly the same as for preparing "corned" alewives, the fish being gutted, washed, drained, and salted into large vats. However the curing time is much longer, taking from 7 to 9 days. During this period the fish are stirred daily with large paddles in the curing vats and if necessary some extra salt is added to maintain the strength of the pickle. After the fish are cured, they are taken from the vats and piled on a draining floor and allowed to drain thoroughly and until partially dry. After 4 to 10 days the fish are weighed or counted and packed in barrels; the first layer is laid backs down and the remainder backs up. About 2 to 2½ pounds of salt are spread over each layer and the fish are tamped lightly to obtain a tight pack. A barrel of "tight-packed" river herring should contain 160 pounds of fish and 40 pounds of salt.

If these salted alewives are to be stored for a considerable length of time, they must be placed in cool or cold storage. The bulk of the pack is shipped immediately to Norfolk or Richmond and held in storage until needed. Even in cold storage, the fish slowly rust and cannot be kept in good condition for more than a year.

The Salting of Mackerel

With the steadily increasing demand for fresh and frozen mackerel in the United States the production of salted mackerel has shown a gradual decline over the years. The American production in 1945 was only 3,573,448 pounds, as compared with 9,045,469 pounds in 1909. However, salted mackerel is still one of the favorite salted fish items in the United States, but the markets are being supplied by imports from Europe, especially from the Scandinavian countries. In 1945 the imports of salted mackerel amounted to 6,169,189 pounds, valued at $846,258.

Although a considerable part of the production is made aboard the fishing vessels in the North Sea, much is now being packed at shore stations located at strategic points along the Norwegian Coast. These coastal mackerel are caught with seines and gill nets and are delivered to the salteries within a few hours. The Norwegian Government has made special efforts to cater to the American market and from time to time has sent travelling instructors to the various districts

to teach the curers the proper procedure for curing mackerel for this market. One of these instuctors, C. S. Haaland (1924), has described the preparation of salted mackerel as follows:

"It is of great importance that the mackerel be brought from the nets to the saltery as quickly as possible, so that they can be handled while in fresh condition, and only enough should be taken at one time so they can be prepared before the fish become soft. If it is necessary to transport the mackerel some distance, they should be handled in boxes containing about 100 pounds each. The fish should be rushed to the plant and work started immediately upon arrival to split and clean them. The splitting proceeds as follows: the mackerel is held in the left hand and with the knife in the right hand it is split along the backbone, with one cut of the knife, from the head to the tail. The gills and all viscera are then removed and the fish thrown in tubs of water to wash away the blood. In order to remove the blood along the backbone each fish is scrubbed with a stiff brush. After scrubbing, the mackerel are placed in other tubs of fresh water for about 3 hours. The water should be changed several times during this soaking. When the fish have soaked until they are white and free from blood, they are dipped out for salting. If the mackerel have not been 'ploughed' or 'reamed' by making a cut on each side of the belly at the time of splitting, this is done now as they are removed from the soaking water. These cuts must be made so shallow that they do not penetrate the skin. In the salting process one person dredges or rouses the mackerel in fine salt; then passes them to another, who lays and salts them in the barrel. For salting it is best to use Mediterranean sea salt, Trapani or St. Ybes, at the rate of 1 barrel of salt to 3 barrels of mackerel. The fish are laid in the barrels, flesh side up with the exception of the two top tiers, which have the skin up. The filled barrels are headed up, filled with brine, and laid on their bilges. It is not advisable to let the barrels stand on end to allow the fish to settle. The recommended procedure is to head, fill, and lay over the barrels as quickly as possible after packing. Care must be taken to see that the barrels are always well filled with brine. At first it may be necessary to refill the brine every other day to be sure that the barrels are tight.

"The mackerel should remain in the salt at least 3 weeks so they are well 'struck' before beginning the repacking for export. In repacking the fish are dumped from the original barrels into a tub or vat of brine to wash off the excess salt and any foreign material that may be present. From the brine they are dumped onto a table of convenient height and sorted into several grades as follows:

No.	0,	up	to	130	fish	per	barrel
"	1,	"	"	180	"	"	"
"	2,	"	"	250	"	"	"
"	3,	"	"	350	"	"	"
"	4,	"	"	450	"	"	"
"	5,	"	"	550	"	"	"

92 kilograms (202 pounds) of a grade are weighed out for each barrel. In repacking the fish are laid as before with the flesh side up, except for the two top tiers, which are skin up. Each layer is sprinkled lightly with salt, using about 1 barrel of salt to 7 or 8 barrels of mackerel. When filled the barrels are headed, filled with 100° Sal. brine, and laid on their sides. For best appearance of the

fish it is advisable to use new salt and fresh brine. For export only good legal barrels should be used. They should be full hooped on both ends and with 2 bungs."

In the United States about half of the production is in the form of salted mackerel fillets. The curing process is quite similar to that outlined above, except that in the butchering the fish are split into two fillets with the backbone removed. In the repacking smaller containers are often used, generally wooden kits of 10-, 25- and 50-pound capacity. Being a luxury item it is packed in these smaller, more convenient packages.

The Salting of Mullet

In poundage the mullet has been, and still is, the leading fish caught in the southern states, with a yearly catch varying from 30 to 40 million pounds. Of this amount only a small part (1,830,800 pounds in 1945) is salted, principally in Florida and North Carolina. Because of the difficulties attendant upon the salting of fish in warm climates the salted fish industry has never flourished in this region. The tendency of salted fish to sour or rust has been especially troublesome.

Two methods of preparing salted mullet are in use: "dry-salting" and "brine-salting."

Dry-Salting. The best method for curing mullet in the warm weather of the southern states is dry-salting (i.e., a combination of salting and drying). If the fish are strictly fresh and handled carefully, the product will be of good quality. The recommended procedure (Jarvis, 1933) is as follows:

The fish should be split along the back, "mackerel style," so that they will lie flat in a single piece, leaving in the backbone. The head may or may not be removed. The viscera are removed, but the roe are saved and salted separately. In cleaning remove all traces of blood from under the backbone and clear away all the black skin. If the head is left on, clean out all traces of the gills. Score each fish longitudinally along the backbone and also through the flesh on the other side. Afterwards the fish should be washed and soaked in a light brine solution for about 30 minutes to remove all traces of blood and slime. They are then taken out of the brine and allowed to drain for about 15 minutes to remove excess moisture. For salting use "dairy fine" mine salt which, for convenience, is placed in a shallow box about 2 feet square. Dredge each fish in the salt, rubbing some into the scored cuts on each side. The fish are then packed, layer by layer, into barrels or tubs with the flesh side up, except the top row, which is reversed. A little salt is sprinkled on the bottom of the container and over each layer. A weight should be placed on top to keep the fish under the surface of the brine that forms. The fish should be allowed to cure in this brine for 36 to 48 hours, at the end of which time they are removed from the barrels or tubs.

After washing in brine to remove excess salt and draining for 15 to 20 minutes the fish are ready for the drying racks. These are frames of wood, covered with chicken wire and standing on legs 3 or 4 feet high; they should, of course, be located on dry ground. Oxidation or rusting sets in immediately if drying is carried on under the direct rays of the sun. But if fish are kept shaded in a breezy location, they will dry well with a clear color. For this reason drying is best done in the shade under a roof without walls, so located that as much of a current of air as possible will pass over the fish. The fish are laid skin side down

to start, but are turned 3 or 4 times the first day. The fish are gathered up and placed under shelter at night to prevent spoilage through dampness, which causes souring and molding. The time required for drying usually averages 4 days, but depends on weather conditions during the drying period and on the size of the fish being cured. The more the fish are dried, the less danger there will be of reddening or rusting. If the surface looks dry and hard and the thumb can be pressed into the thick part of the flesh without leaving an impression, the fish can be considered cured.

Should high humidities make air-drying impossible, the following method may be used: When the fish are "struck through," or have absorbed enough salt for curing purposes, they should be taken out of the salt, scrubbed off in brine, and piled in stacks, flesh side down. These stacks should be heavily weighted in order to press moisture out of the fish. After 10 to 18 hours in the stack the fish should be repacked in dry salt, weighted down, and then put in storage in a cool dry place.

Brine-Salting. In an effort to stimulate the production and use of brine-salted mullet in the southern states technicians (Lee and Young, 1943) of the U. S. Fish and Wildlife Service have devoted considerable time to a study of methods of curing. Their recommended procedure may be summarized as follows:

In the preparation of brine-salted mullet the fish should be dressed as soon as possible (within 6 hours at the most) after removal from the nets or seines. The fish are split down the back and along the backbone; the heads are cut through so that the fish can be laid out flat. The viscera are now readily pulled out. The roe, in season, are usually separated and dried, salted or smoked, as a profitable by-product. The gills are removed, and the appearance of the product is improved if the black membrane is also removed. The heads and foreparts of the backbone are often taken out of larger fish (those weighing more than 1½ pounds). After removal of the viscera the fish are washed in clean sea water or light brine to remove blood and slime. Soaking for half an hour in brine will make the cleaning operation simpler.

The fish are now ready for salting, for which purpose a mined or refined salt is preferable to sea salt, as it is cleaner and contains less chemical impurities. The ocean salts are also carriers of the bacteria that cause reddening of the fish. In packing, a heavy layer of salt is placed on the bottom of the barrel and is covered by a layer of fish, open side up. This layer is then liberally sprinkled with salt and the second layer of fish added. The operation is repeated until the barrel is full. The fish are usually packed fanwise, with heads out and tails toward the center. Care is taken that they do not overlap. Every surface should be exposed to the action of the salt. The top layer of fish is placed cut side down, covered with salt, and weighted to keep the fish submerged in the brine that forms. The fish should be "struck through" with the salt within 4 to 10 days, depending upon the size of the fish. If possible the fish should be held in a cool room at a temperature not exceeding 50° F (10° C) during the "striking through" period.

Repacking can be done any time after the fish are struck. They are graded and sorted for size and condition, and any remaining blood, salt, scales, and slime are rinsed off in brine. The clean fish, with a layer of salt on the top and bottom and a slight sprinkling of salt between layers, are now packed in the smaller

buckets, kegs, or barrels in which they are sold. The containers are then headed up and filled with concentrated brine. Storage should be in a cool place, and constant care to keep the mullet at all times under a protective cover of brine is made necessary by the high fat content of the flesh.

The Salting of Lake Herring

Large quantities of lake herring, trout, whitefish, pike, pickerel, saugers, suckers, and other species of Great Lakes fish were formerly salted each year, but the increased trade in the fresh- and frozen-fish business has resulted in a large decrease in the production of salted fish. Except for small amounts of lake trout the present packing is limited to lake herring. Statistics for 1945 showed that a total production of this species amounted to 5,036,574 pounds, valued at $158,988, the industry being centered largely in Michigan and Wisconsin.

The methods of salting lake herring are essentially the same as have been previously described for other species. The fish may be slit down the belly sufficiently to remove the viscera and cured in a manner similar to split herring; or they may be split and salted "mackerel style." In either case, though, the heads are generally removed. The fish are packed in barrels and cured in their own brine. After "striking through" (4 to 6 days) they can be removed from the original containers for repacking. After washing in brine to remove excess salt, etc. the fish are repacked in smaller barrels, usually of 100-pound capacity. A light sprinkling of salt is placed on the bottom and top, as well as over each tier of fish. After filling the barrels with 100° Sal. brine they are ready for shipping. Storage should be in a cool place at all times.

Miscellaneous Fishes

In addition to the fishes discussed above, others are salted commercially in the United States in limited quantities, often for the local trade. Chief among these are the following: albacore or tuna, barracuda, bonito, blue runner, eel, hogchoker, jewfish, paddlefish, pilchard, sablefish, sea bass, sea trout, and spot. Complete statistics relative to the quantity and value of these fishes salted annually in the United States are not available; however, in Table 90 (p. 376) are presented data for some of those listed.

Because of lack of space descriptions of the methods used in salting each of these fish cannot be included. These methods, although usually differing somewhat in various localities, are modifications of the general processes already discussed in some detail.

REFERENCES

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

Anon., "Scotch Cure of Herring," *Alaska Publicity Bureau Bull.*, 4 (1921).

Anon., "Herring and Allied Species, 1920–48," Food and Agriculture Organization of the United Nations, *First Progress Report* (1949).

Cobb, J. N., "Pacific Salmon Fisheries," U. S. Bureau of Fisheries *Doc.*, **902** (1921).

Haaland, C. S., "Salting of Mackerel," *Aarsberetning vedkommende Norges Fiskerier 1924*, **I**, 34 (1924).

Jarvis, N. D., "Method of Dry Salting Fish in Southern States," U. S. Bureau of Fisheries *Mem.*, **S** 332 (1933).

Jarvis, N. D., "Curing of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.* **18** (1950).

Jarvis, N. D., and Hines, R. W., "Salting River Herring in the Chesapeake Bay," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **26** (1945).

Jenkins, J. T., "The Herring and the Herring Fisheries," London, P. S. King and Son, Ltd., 1927.

Kolloen, L. N., "The Decline and Rehabilitation of Southeastern Alaska Herring Fishery," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **252** (1947).

Lee, C. F., and Young, L., "Brine-Salted Mullet Has Unrealized Possibilities," *Food Industries,* **15**, No. 11, 70–71, 144–145 (1943).

Preger, A. W., "The Humble Dutch Herring," Melbourne, F. W. Cheshire Pty., Ltd., 1944.

Sea Fish Commission for the United Kingdom, "The Herring Industry," London, 1934.

Taylor, H. F., "Improvements in Process of Salting River Herring Especially Adapted to Warm Climates," U. S. Bureau of Fisheries *Doc.,* **903** (1921).

Tressler, D. K., "Some Considerations Concerning the Salting of Fish," U. S. Bureau of Fisheries *Doc.,* **884** (1920).

Tressler, D. K., "The Wealth of the Sea," New York, Appleton-Century-Crofts, 1927.

CHAPTER 19

The Preservation of Fish by Smoking and Drying

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An Introduction to Fish Curing

Destruction of Bacteria and Enzymes

Since the decomposition or breakdown of fresh fish flesh is primarily due to the action of bacteria and enzymes, the principal consideration in all methods of fish curing is to destroy both of them completely, or, failing in this, to reduce or inhibit the growth of the bacteria and the autolytic action of the enzymes to such a point that spoilage progresses so slowly that the prepared product will be marketable over a reasonable period of time. This may be accomplished in several ways.

Low Temperatures. Temperatures between 70 and 100° F (21.1 and 37.8° C) seem to be the most favorable for the multiplication of the common putrefactive bacteria. As the temperature is decreased progressively below 70° F (21.2° C), bacterial decomposition is gradually retarded until at points below freezing it ceases entirely for all practical purposes. Enzymatic spoilage is retarded at moderate storage temperatures, but becomes negligible only at a very low temperature (– 40° F [– 40° C]).

This is the basic principle recognized in the preservation of fish by icing and freezing. In curing fishery products low temperatures are often of value in holding the raw fish before preparation and in subsequent storage after curing; they are used for mild-salted, spiced, pickled, and smoked products.

High Temperatures. The application of heat will likewise inhibit both putrefaction caused by microorganisms and autolysis due to enzymes. When proper temperature and length of exposure are utilized, both of these spoilage processes can be completely checked. Canning of fishery products is, of course, the classical example of the use of this principle. In the hot-smoking of certain kinds of fish sufficiently high temperatures are employed so that enzymes are completely in-

activated and most yeasts and molds and many bacteria that may be present are killed.

Removal of Moisture. The fundamental principle involved in the preservation of most cured fishery products is dependent on the fact that moisture is highly essential for both general types of spoilage—putrefaction and autolysis. As moisture is gradually removed from fish flesh, decomposition due to bacteria and enzymes is progressively retarded. If this dehydration is carried far enough, both actions will be completely checked.

Only in a few dried products is this stage reached. In the vast majority of cured fish products the decomposition or breakdown of the protein material is only inhibited or retarded to a greater or lesser degree, depending on the amount of moisture removed. The keeping qualities will therefore vary greatly. Lightly smoked products, such as finnan haddie and smoked fillets, spoil almost as readily as fresh fish, while thoroughly dried stockfish will keep for several years. As mentioned previously, the holding of prepared products in cold storage after curing is essential. In fact without the use of refrigeration the market for many kinds of cured fish would be strictly of a local nature.

Antiseptics. The action of microorganisms and enzymes can be inhibited by the use of certain antiseptics, the principal one used commercially being acetic acid which is found in all vinegars. In order to stop decomposition completely the acid content of the vinegar would have to be so great that the finished product would become inedible. Even though spoilage of pickled fish proceeds slowly after preparation, the use of low temperatures for storage is advisable at all times. Benzoate of soda, sodium nitrate, sodium nitrite, and other preservatives have limited use in a few fish-curing processes. Smoke also has antiseptic properties.

Elimination of Air. While strictly speaking the elimination of air is not a basic principle involved in the actual curing processes, it prevents certain physical and chemical changes during storage which would spoil the finished product. In storing many kinds of salt fish, especially those of an oily nature, it is most important to keep the product covered with brine to prevent exposure to the air, which would lead to the oxidation or "rusting" of the oil and subsequent spoilage. Artificially dried fish also exhibit better keeping qualities when stored in the absence of air, such as in a vacuum-sealed can.

Methods of Removing Moisture

Although in the preparation and storage of many varieties of cured-fish products all 5 basic principles may be utilized, the fundamental one involved in the actual curing processes is the removal of moisture, which is found in the flesh of all fish and which constitutes 60 per cent or more of the total weight. The removal of this water may be effected in one or more of the following ways:

Exposure to Currents of Air. This may be done in the open air by utilizing the natural wind currents; in ovens where drafts are created by the burning of wood fires or other forms of heat; or in specially designed driers in which the air currents are created by artificial means. Typical of this application are the various kinds of dried and dehydrated marine products.

Osmosis. This is the term commonly applied to that natural phenomenon occurring in all forms of plant and animal life, whereby nutrients in solution are able to pass through the cell membranes into the body and at the same time cer-

tain other substances pass out. Different types of membranes exhibit varying degrees of selectivity of the substances which are able to diffuse. This osmotic process occurs when fish are placed in a strong salt solution. The selectivity of the skin and cell membranes of the flesh is such that as water passes out some salt passes in, while practically all the essential food materials are retained within the cells. This principle of osmosis is therefore exemplified in all common salting processes, and also in the first step (brining) of nearly all smoking processes.

Use of Pressure. In some curing processes water is mechanically removed by the exertion of pressure upon the fish. Piling and repiling cured fish in stacks, with or without the use of added weights, is a common method of preparing dried salted codfish. In the preparation of pressed sardines (salachini) the moisture is extracted by means of machines or presses of various types.

Application of Heat. Ordinarily heat is applied to stop, or at least retard, bacterial and enzymatic spoilage. However, in the cooking of fish, as in hot-smoking, a part of the water is removed, which in itself is an aid to preservation. In preparing certain kinds of dried fish products a preliminary cooking, such as steaming or boiling in water, is common practice and results in the removal of substantial amounts of moisture before the actual drying process takes place.

Absorption Through Use of Blotter-Like Pads. This interesting application found some use years ago in curing dried codfish, but so far as known is not being used commercially today.

In preparing most dried fish moisture is removed by the application of one method only: exposure to currents of air. Likewise in the salt curing of many marine products the entire process is dependent on the principle of osmosis, through the action of the salt applied. However, in many other cured items two or more methods of removing moisture are employed; for example, various smoking processes may make use of osmosis, pressure, and exposure to currents of air and heat.

Fish Smoking

Introduction

Although the origin of fish smoking is obscured by antiquity, aboriginal man must have developed this method of preserving his catch from the sea shortly after he discovered how to make fire. Undoubtedly one of the first foods that our primitive ancestor learned to cook on an open wood fire was some form of fish that he had succeeded in capturing by hand. Experience soon told him that this barbecuing process not only made his food keep longer, but also added a distinctive flavor. As time went on it became evident that the flavor varied with the kind of wood burned, and those which gave the most pleasing flavor were soon discovered. Other improvements followed gradually. Proper timing of the barbecuing and correct temperatures, or to primitive man the correct position of the fish with respect to the fire, were determined. As man became familiar with the use of salt, he found that a preliminary salting or brining further improved the flavor and keeping qualities of his fish products prepared over a wood fire.

If records were available, from this crude beginning could be traced the evolution of present methods of hot-smoking or barbecuing, as it is sometimes called.

Surprisingly enough it was not until the development in the last few years of modern controlled smokehouses that any real advances have been made over these primitive methods. In fact, in as progressive a country as the United States, it is safe to say that the majority of its smoked fish products are still being prepared by empirical methods. Except for the addition of roof and walls around the fish and fires these processes do not show great improvement on those used by the aborigine.

About the time man was learning how to barbecue fish, or perhaps earlier, he discovered the possibilities of drying fish in the open air. Like his modern counterpart ancient man found that one of the hazards of open-air drying was the development of maggots in his finished product. If the prevailing winds failed him before his fish could dry and form a firm crust, the ever-present flies were ready for action. Possibly by chance he discovered that a wood smudge burning under his hanging fish not only eliminated the peril of fly-blowing, but imparted a smoky flavor.

With certain types of fish the smoke flavor was preferred; thus a smudge fire under the drying fish became an essential part of the process. Use of proper wood, regulation of the heat of the fire, and density of the smoke, together with a preliminary salting or brining, completed the evolution of what is known as cold-smoking. As in hot-smoking, the only appreciable advance modern man has made over these primitive open-air smokeries is the addition of a roof and walls around the fish and fire. Controlled processes based on scientific principles are just beginning to come into use in fish smoking.

In the United States production by this method of preservation has never equaled in value or quantity that preserved by other methods, such as salting, canning, and freezing. Figures for 1945 (Anon., 1945), as shown in Table 91 (p. 398), indicate a total output of smoked fishery products in the United States and Alaska of almost 30 million pounds, valued at more than 8 million dollars.

Principles of Smoke Curing

The production of a so-called smoked fishery product actually involves far more than the application of smoke. In general four interrelated processes are necessary: (1) salting, (2) drying, (3) heat treatment, and (4) smoking (Shewan, 1945). The quality of the final product depends upon the proper care and control of each of these processes. The final quality depends also upon the species of fish to be smoked and the freshness of the original raw material.

Salting. Salting the product prior to smoking is usually accomplished by soaking the fish in a brine for a definite length of time. The strength of the brine used will vary with the type of cure, and may vary with the species of fish and the length of the salt cure.

Brining aids in several ways. First of all it tends to firm the fish by removal of moisture and by some denaturation of the proteins. In certain concentrations salt tends to inhibit the growth of bacteria, and at times fish may be salted prior to smoking and held in this condition until the smoking process is applied. Salt also imparts a flavor to the product. In cures, such as used with herring and in the mild-curing of salmon, the fish are held in a brine of a definite salt concentration and at a suitable temperature so that the desirable "cured" flavor may be obtained. The duration of the brining process and the concentration and purity of the

TABLE 91. SMOKED FISHERY PRODUCTS IN THE U. S. 1945.

Item	Quantity lbs.	Value
Alewives	145,625	$ 7,508
Amberjack	500	65
Bluefish	300	45
Blue marlin	300	66
Buffalo fish	350,700	74,445
Butterfish	480,700	112,350
Carp	172,917	50,187
Catfish and bullheads	7,800	1,560
Chub, ciscos, and tullibee	5,326,872	1,628,429
Cod	516,180	63,776
Cusk	402,599	32,137
Eels	225,355	61,539
Flounders	1,800	290
Haddock	912,691	122,215
Hake	39,400	1,227
Herring, lake	1,082,397	135,262
Herring, sea	3,635,681	387,773
King mackerel	9,000	2,175
Lake trout	887,271	273,277
Mackerel	64,200	13,050
Mullet	33,100	6,765
Paddlefish	147,500	60,850
Sablefish	561,995	158,414
Salmon	11,001,654	3,608,830
Shad	236,808	207,365
Sheepshead	24,217	3,417
Sturgeon	713,633	457,245
Suckers	2,000	150
Wahoo	300	65
Whitefish, common	2,641,069	875,288
Whitefish, Menominee	16,000	4,000
Yellow perch	600	150
Yellow pike	600	150
Shrimp	500	250
Unclassified	335,406	37,918
Sailfish	10,200	2,142
Total	29,987,870	$8,390,375

Source: Anon., "Manufactured Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Statistics* 434 (1945).

salt are quite important factors in curing fish. These factors, therefore, must be accurately and carefully controlled.

Fish may be lightly or heavily brined, depending upon the type of product to be prepared. Lightly salted fish should be smoked immediately since the brining serves merely to impart a desirable flavor and to firm the flesh. This preliminary firming of the flesh aids in the formation of a "pellicle" which fully develops in the smoking process.

Heavy brining is used in the development of special cures, as, for example, in the mild-curing of salmon and for preserving fish until the smoke-curing process can be applied. In this type of cure the salt concentration of the fish reaches 8 to 10 per cent. However, this concentration of salt, in itself, is not sufficient to preserve the fish indefinitely, and the product must be held at low temperatures, preferably about 32 to 34° F (0 to 1.1° C). Most of this salt must be removed from the fish prior to smoking. This is accomplished by soaking the fish in cold running water. The efficiency of the soaking will, of course, depend upon the volume of water, temperature, and length of time. The control of these factors is also important.

Drying. After suitable brining (and soaking, if necessary) the fish are subjected to a drying process. This is necessary to remove additional moisture, thus aiding in the preservation of the product and the formation of the "pellicle." Under similar conditions of time, temperature, air flow, and humidity the more moisture removed from the fish the greater the keeping quality. The moisture content of most smoked products averages 60 to 75 per cent which is much above the critical moisture content necessary for the growth of microorganisms. The beneficial effect of drying is confined to the surface of the product. Drying is usually accomplished in the smoking chamber and the maintenance of the proper humidity is quite important. It has been found that in an atmosphere of relative humidity above 75 per cent very little drying of the fish will occur (Cutting, 1942).

Drying aids in and is partially responsible for "pellicle" formation. The "pellicle" is the glossy firm surface imparted to the fish which gives it the required desirable appearance and allows for the development and absorption of the delicate smoke flavor. Formation of this "pellicle" is quite important in securing a smoked product of good quality.

Heat Treatment. Fish may be smoked in a cold or hot atmosphere, depending upon the type of product desired. Cold-smoking, which produces a product which is generally referred to by the trade as *smoked*, is accomplished in an atmosphere below 85 to 90° F (29.4 to 32.2° C). In this case there can be no preservative effect attributed to the heat treatment. The amount of fat present in the flesh and the method of preliminary cure affects the temperatures which may be tolerated without cooking. A fatty fish with a cure such as that of mild-cured salmon may tolerate temperatures in the neighborhood of only 80 to 85° F (26.7 to 29.4° C); while lean, lightly brined haddock, used in the preparation of finnan haddie, is best produced at temperatures around 90° F (32.2° C). These products are highly perishable and must be kept under refrigeration, preferably at 32° (0° C) below, at all times.

Hot smoking produces the well-known *kippered* or barbecued items. These fish are actually cooked or barbecued, and temperatures range from 120 to 180° F (48.9 to 82.2° C), with some fish being smoked at even higher temperatures. The heat destroys the enzymes producing autolytic changes and also coagulates the proteins throughout the entire product. Molds are destroyed and most bacteria are killed. In addition the removal of moisture is aided by this heat treatment since the more the temperature is increased above atmospheric, the greater the rate of diffusion of moisture through the fish to the surface, from which it escapes to the air. As barbecued fish are cooked as well as smoked, they do not require any further preparation before eating.

Smoking. The primary purpose of smoking is to impart to the fish the particularly desirable smoked flavor and color. Little preservative action is afforded by the smoking process. Some antioxidants may be imparted to the fat (Stansby and Griffiths, 1943); however, as salting tends to increase the susceptibility to oxidation, the beneficial effects of the deposited antioxidants are thereby overcome. The preservative action of the deposited constituents of the smoke is only slight although phenols, aldehydes, and possibly the fatty acids in the concentrations deposited on the fish may serve as mild antiseptics (Shewan, 1945). This inhibitive action on bacteria is most effective on the surface of the fish, especially when the smoke concentration and length of exposure are increased (Hess, 1928). It must be emphasized that despite the beneficial effects of brining, drying, and smoking, smoked fishery products are highly perishable and should be held under refrigeration at all times.

It is believed that the deposited phenols are responsible for the formation of the color of smoked products (Linton and French, 1945). These compounds, usually found in wood smoke, tend to darken to a deep brown color on exposure to oxygen. This then is probably the reaction that takes place after these substances are deposited on the fish during the curing process.

For smoking, almost any kind of hardwood, such as oak, alder, hickory, mahogany, etc., may be used. Softwoods are not recommended because of their resinous nature and their tendency to deposit acrid flavors and odors on the smoked products (Sidaway, 1944). The quality of the smoke produced by any type of wood may vary considerably with the control of conditions within the smoke generator itself. In general two types of smoke may be produced in a generator-"distilled" smoke and "blown" smoke (Cooper and Linton, 1934). The distilled or wet dense smoke is produced as a result of a low rate of combustion of the wood. This is caused by allowing only a small amount of air to enter the generator during the smoking process. The dense gray smoke contains much moisture and does, thereby, allow for less shrinkage in the smoked fish. This is not necessarily an advantage since some drying of the fish must occur to permit the formation of a suitable pellicle and to yield a smoked product of good quality.

The distilled smoke produces a heavy dark pellicle and imparts a bitter, acrid taste to the product since it contains more resinous material and acids. The "blown" smoke is produced by a more complete combustion of the wood. It is a lighter smoke, containing more of the desirable products of combustion which tend to produce a smoked product of good flavor and color. This type of smoke usually contains less moisture and therefore aids in drying the fish. As a result a more suitable pellicle is formed, giving the fish the desirable texture, color, and flavor.

Other methods of imparting smoke flavor to fish products, such as by the use of liquid smoke flavor and by electrodeposition of the constituents of smoke, have been suggested. Liquid smoke flavors have not proved entirely satisfactory, but may be used for certain particular cases. The process for the electrodeposition of smoke flavor is still in the experimental stage, but is adaptable primarily for imparting smoke flavor to fish products prior to canning.

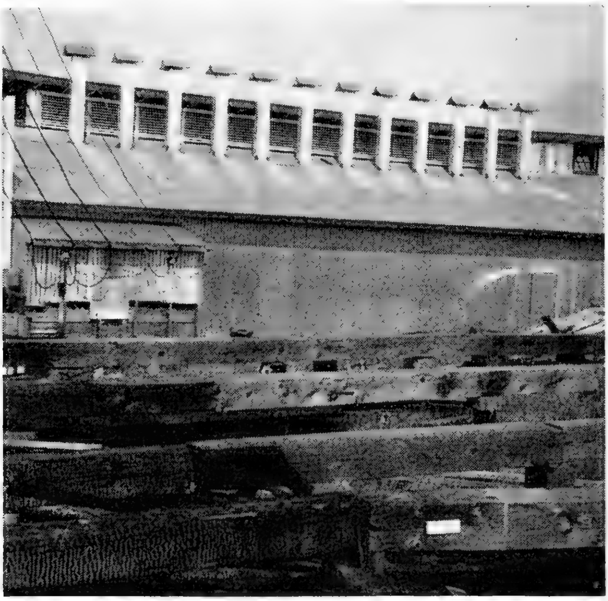
The amount of smoke curing applied to the fish is dependent upon the type of product desired and upon the species of fish used. Some fish contain different amounts of oil or fat, and their salting and smoke curing may need to be ad-

justed accordingly. Small fish may require as much smoke as a larger fish of the same type, but the amount of drying may be varied. Those fishery products smoked prior to canning are smoked only lightly, that is, just sufficient to produce the desired smoke flavor. Canning and subsequent storage tend to enhance the smoke flavor. In order to yield a product of suitable texture and appearance some canned fish must first be hot-smoked prior to canning to remove moisture.

The original quality or freshness of the fish is decidedly important. Only fresh fish of good quality should be used. It was discovered that fish which have been out of "rigor" for a short time take on a better and more permanent sheen than those strictly fresh (Cooper and Linton, 1934).

Smokehouses

The type of smokehouse used is usually determined by the quantity of fish to be smoked. They may be of almost any shape or size. For production of small lots a large barrel or tierce is used as a kiln. The top and bottom of the barrel or tierce is removed and the shell placed over the smoking pit. For cold smoking the pit is located some distance from the barrel, but is connected with it by a large



(Photo by R. K. Pedersen)

Fig. 19–1. Old-fashioned kiln-type smokehouse.

diameter pipe or tunnel. Rods for holding the fish are placed across the top. When the smoking process is well under way, a sack or cloth is placed over the top of the barrel to control to a certain extent the concentration and volume of smoke passing through the smoking chamber.

The smoking of larger, commercial quantities of fish necessitates a much larger installation, and for this a shedlike structure or a complete building is often used. In the United States a typical house is about 15 to 20 feet wide, 20 to 25 feet

long, and 30 feet or more high. In many commercial plants these may be incorporated within larger buildings and are often two or three stories high. The older types are constructed of wood, except possibly for the fire pit, which is of brick. Other types are completely constructed of brick or other fireproof material, which is more desirable for the smoking process since it eliminates the fire hazard. Air-smoke circulation is maintained by natural draft; the fire pit is equipped with dampers to control air intake, while adjustable louvers are located near the roof to allow removal of surplus smoke and moisture-laden air. By these means air-smoke circulation can be controlled to a limited extent, but is dependent considerably upon external weather conditions, size of the fire, and height of the smokehouse.

Temperature and humidity are controlled to a limited extent by adjustment of the dampers and louvers and size of the fire, but these factors also depend upon prevailing weather conditions. In winter the smokehouse temperature may fall so low as to require a fairly hot fire. An extremely hot fire causes too rapid and complete combustion of the wood or sawdust, thereby reducing the quality of the smoke for curing. In warm weather too low a fire may be necessary, causing a dense wet smoke which also tends to produce an inferior smoked product. In some of the larger towering kilns the fish nearest the fire are cured much faster than those near the roof; considerable handling is therefore necessary to give a uniformly cured product. With the wood fire directly below the fish there is a tendency for soot and flying ash to deposit on the fish, rendering the product inferior. Despite the many disadvantages of the old-style smokehouses, excellent products have been and still are being produced in them. However, this can be accomplished only on a uniform basis by a seasoned and careful operator who has had long experience with the particular type of smokehouse that is being used.

Controlled Smoking. The preceding discussion on kiln smoking indicates that few scientific principles have been applied to the process. Very little attention has been paid to the accurate control of each individual procedure involved. In fact the very construction of the smokehouse makes accurate control difficult to attain. There are four main variables in the smoking procedure which must be subject to control. In the designs of the various so-called controlled smokehouses attempts are made to incorporate all the equipment necessary to accomplish this end. These variables are: (1) smoke volume and quality, (2) temperature, (3) humidity, and (4) air velocity and distribution.

The generated smoke must be clean and free of soot, grit, and ash. The generator may be located adjacent to or some distance from the smokehouse proper. It should be equipped with suitable dampers and ventilators to insure proper combustion of the wood and control of smoke density. A metal box or drum may be used for the generator. The smoke must be delivered to the house through a large diameter pipe to allow for the condensation of tars and resins and to prevent clogging due to deposition of these products. Traps for catching and draining these materials should be located at convenient places along this pipe line.

The smokehouse proper should be constructed of fireproof material and sufficiently insulated to keep any heat loss to a minimum. Some heat may be derived from the smoke generator, but additional heating units should be installed in the smokehouse to allow for accurate temperature control and for drying or cooking the fish. Proper temperatures should be maintained by thermostatic control.

The humidity may be controlled to a limited extent by regulating the smoke generator, the temperature within the smokehouse, and the air circulation, and by adjusting the exhaust dampers. The efficiency of these operations is dependent upon external atmospheric conditions. In moist atmosphere it will be necessary to remove moisture from the air before it enters the smoking chamber. This is accomplished by installing a cooling system ahead of the air intake. Warm air can hold more moisture than cold air. The indrawn air is first passed over cold coils or chopped ice to remove most of the moisture. This cold dry air must be preheated before entering the smoking chamber. The smoke unit should be equipped with an exhaust damper to allow for the removal of moisture-laden air.

Air-smoke velocity and distribution within the smoking chamber are very important factors in the proper curing of fish. The preliminary drying air and the air-smoke mixture velocities can be controlled by a variable-speed volume blower or fan. Louvers should be located at proper positions to direct an even flow of air-smoke through the smoking chamber. Damper control aids in the removal of excess air, smoke, and moisture and also recirculates smoke to prevent waste. Proper air-smoke distribution eliminates the so-called "banding" or uneven curing of the product. Air velocity must not be too great, otherwise heat is wasted and excess drying of the product results. In this connection it is important that the smokehouse is not overloaded or the fish arranged so as to prevent suitable circulation of the smoke.

In general a smokehouse embodying the principles of controlled smoking should be designed so as to be adaptable for any type or form of fish or fishery product. Installation of automatic temperature and humidity indicators is desirable. Automatic control of chamber temperature is an advantage, and manual control of air velocity, smoke density, and dampers is suitable.

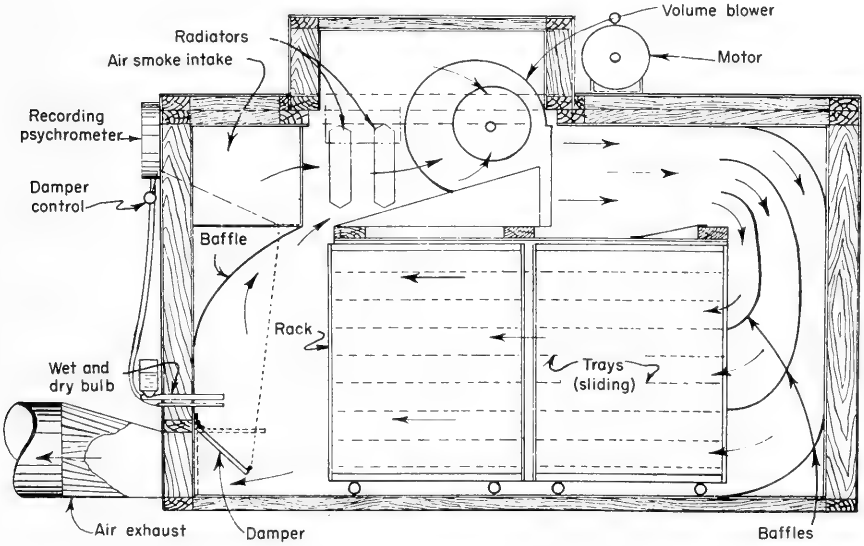


FIG. 19–2. Diagram of controlled smokehouse designed by C. L. Anderson indicating path of smoke.

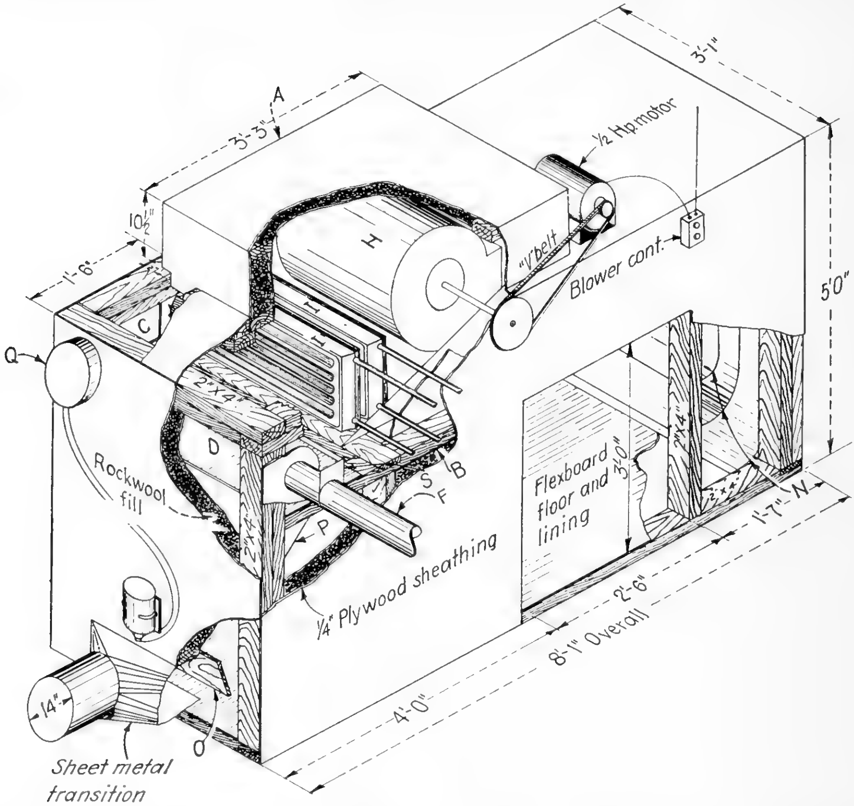


FIG. 19–3. Plan of controlled smokehouse indicating dimensions and materials of construction.

Advantages of Controlled Smoking. The controlled smokehouse offers many decided advantages over the old-fashioned smokehouse:

1. It is a compact unit, allowing a considerable saving in space. This is particularly important in plants of limited size and in established plants contemplating the installation of a smokehouse. A unit of suitable size could be installed in an unused portion of the plant without interfering with regular operations.

2. It is equipped for complete control of the smoking procedure which allows for the preparation of a consistently uniform product of good quality.

3. There is a saving in labor requirements and cost since all operations are conducted on one floor. Uniform curing through all sections of the smokehouse chambers eliminates considerable handling; once the trays are loaded with fish for smoking, there is no need for further rearranging or shifting of the product.

4. It permits a shorter total smoking time as a result of more uniform temperature control, high rate of air-smoke velocity, and proper humidity control.

5. Through recirculation of the smoke and insulation of the unit the smoking time is reduced and wood and fuel consumption is thereby saved.

6. The fire hazard is minimized since the smoke generator is a separate unit

located a suitable distance from the main house and the smoking chamber is of fireproof construction.

7. Waste of the smoked product, usually caused by flying ash and dropping on the floor, is reduced.

8. The controlled smokehouse is adaptable; that is, it may be used for any species or form of fish.

Many controlled smokehouses are now in use both here and abroad. The Torrey Research Station in Scotland has developed a very large, well-designed structure that has been widely approved and is being adopted by the large Scottish smoked fish industry, as well as by the industry in other parts of the world. The Norwegians have also perfected kilns embodying many of the features necessary to controlled smoking, especially for smoking prior to canning. Both the Atlantic and the Pacific Stations of the Fisheries Research Board of Canada have built controlled smoke ovens for fish curing. In the United States several types of controlled meat-smoking apparatus have been placed on the market, some of which have been used more or less successfully for curing fish.

During the war years there arose in the Pacific Northwest a considerable trade in smoked canned fish products. Some of these items were cold-smoked and others hot-smoked before canning. Some were processed in chunks or small pieces and others in large pieces or sides. In an effort to devise a smoke oven flexible enough to meet these conditions and at the same time be relatively simple and inexpensive to build the senior author of this chapter developed an oven that has been widely accepted in the Pacific Northwest. Details of a pilot plant are described by Anderson and Pedersen (1947). Since publication of this report several additional plants have been built in other parts of the United States.

In all the above there is no radical change in the time-honored processes of smoking, but merely attempts to control the variable factors that often made the old-fashioned methods unreliable. However, in recent years some new procedures, such as vacuum- and precipitation-smoking, have been introduced; these are based on entirely different principles. Of interest in this connection is the electrostatic precipitation process for smoked sardines.

Large scale canning of smoked Maine sardines has necessitated a quick method of smoking the product, and developmental work by the University of Maine and the U. S. Fish and Wildlife Service has led to the use of an electrostatic device (Hamm and Rust, 1947). In this process the filled cans are conveyed through the smoking chamber; as they pass through, they form the negative side of an electric field of 14,000 to 23,000 volts. In about 12 seconds the fish are sufficiently smoked. The cans then continue on the conveyor to be filled with oil and sealed. The greatest difficulty encountered in this process is in the production of smoke of the desired quality. If there is any flame present in the smoke-producing fire, there is a tendency for soot to deposit on the fish in the precipitation chamber.

Smoke-Curing Processes

It must be emphasized that only fish or shellfish of good quality should be used for smoke-curing. Smoking will not mask or conceal the poor flavor and quality of inferior raw material. The strictest sanitation should be maintained at all points in the procedure. Most smoked and kippered fish are perishable and should be handled accordingly. Careless handling will result in a product of poor

quality and short keeping time. Clean utensils, as well as clean, pure salt and water, should be used in all brining and washing processes.

The smoke cure may be, as previously stated, either cold or hot. Cold smoking, which is accomplished at temperatures below 90° F (32.2° C), may in turn be divided into two general types, depending upon the preliminary brining or salting (i.e., whether the fish receive a heavy or a light salt curing previous to smoking).

Cold-Smoking (Heavy Salt Cure). Fish which are cured and smoked in this manner have fair to excellent keeping qualities, depending upon the length of the salting and smoking operations. After this heavy preliminary salting the texture and taste of the final product little resemble that of the fresh raw material. Preparation of a number of typical examples will be described in the following. In all cases reference is made to procedures used in old-style smokehouses, unless otherwise stated. In a controlled oven the time is always less, and other details may have to be varied slightly.

Smoked Salmon. Cold-smoked salmon, or just "smoked salmon" as it is known in the trade, is prepared almost exclusively from king salmon sides that have been subjected to a preliminary mild-curing process, as described in the chapter on fish salting. Mild-cured salmon has been used extensively for smoking in Germany, England, and the Scandinavian countries. However, the largest market is in the urban areas of the eastern part of the United States, especially in the large Jewish centers, where smoked salmon or "lax" is part of the daily diet. Lesser amounts are smoked in the Middle West and on the Pacific Coast.

Before the mild-cured sides can be given the smoke cure, it is necessary to remove the excess salt. This is done by soaking or freshening the sides in a tank of running cold water for a period of 12 to 24 hours, depending on how long the salmon has been in brine and on the demands of the trade. After proper freshening the sides are trimmed of any rough edges and then given a final wash with a soft cloth to remove any attached foreign particles. It is customary to pile the sides on a platform for a short while before hanging in the smoke oven. This pressing or "waterhorsing" serves a dual purpose because pressure not only removes considerable moisture, but also smooths the cut surfaces of the fish, all of which makes for better appearance and quicker smoking. Some smokers eliminate this step by hand-pressing and smoothing each side as it is being hung in the oven.

The salmon sides are hung from rods placed across the smoke oven at a sufficient height above the fires to avoid danger of overheating. Hanging is done by means of a special type of steel wire hook, having one end curved to fit over a rod and the other equipped with 6 sharp prongs which penetrate the skin and flesh near the nape. Care should be exercised that the sides do not touch one another. Crowding or overloading of the oven should be avoided as it might interfere with proper air circulation.

The first fires that are kindled under the salmon should be "drying" fires, in which the combustion is quite complete (i.e., those that produce "blown" smoke). All drafts and ventilators should be opened and the drying continued until all surface moisture is removed and a glossy pellicle has been formed. The time required will be 24 to 48 hours, depending on weather conditions. This is followed by building fires which smoke heavily, in which a considerable amount of sawdust is generally used. The drafts and ventilators are almost closed so that

combustion is incomplete and "distilled" smoke is produced. During this stage, which takes from 1 to 3 days, depending on the local market requirements, the sides will assume a distinct smoky flavor and the color will darken. The temperature of the smokehouse should be held below 85° F (29.4° C). If the sides are exceptionally fat and oily, it may be necessary to keep the temperature below 80° F (26.7° C) to prevent excessive drip. The weight loss or shrinkage from the mild-cure weight during smoking will run from 0 to 30 per cent, depending on the length of cure and the size and quality of the sides.

After smoking the sides are wrapped in oilproof paper and packed for shipment in boxes to a net weight of approximately 30 pounds. Smoked salmon is perishable and should be stored at 33 to 40° F. Storage below freezing at 0° F (– 17.8° C) is not detrimental if the period of storage is not extensive. In an endeavor to broaden the market and as an aid to the retailer in merchandising smoked salmon, several fish smokers now package sliced smoked salmon in 1- and 5-pound tin cans. Although the cans are hermetically sealed, they are not heat processed and should, therefore, be stored and displayed under refrigeration.

Hard-Smoked Salmon. This product, which is sometimes referred to as "Indian smoked" or "Indian style," undoubtedly originated in an effort to copy the dried salmon of the west coast natives. These aborigines probably used fires or smudges more to prevent fly-blowing than to obtain flavor. At any rate shortly after the repeal of prohibition several enterprising westerners hit upon the idea of packaging sliced salmon in small cellophane bags for the beer tavern trade. It became evident at once that ordinary smoked salmon, as prepared from the mild-cured product, was unsuitable for this purpose because of its high oil content and soft texture. Attention was directed to a drier species, the chum or dog salmon, which proved to be highly satisfactory. However, other species may be used successfully if taken at a time when the oil content is low (i.e., relatively close to the spawning period).

Hard-salted salmon may be used, but a better product can be prepared by starting with fresh or frozen salmon. By so doing the smoker can control the preliminary salting himself and thereby secure the maximum extraction of moisture from the flesh. After the salmon have been split into 2 sides, with the backbones removed, and thoroughly cleaned and washed, they are salted in barrels or tierces (some prefer dry-salting) for 3 to 5 days. This is followed by a soaking in fresh water for a few hours to remove the slight excess salt near the surface of the fish. Hard-salted salmon must be soaked 24 to 48 hours, and difficulty is experienced in getting a uniform freshening.

After draining and "waterhorsing" (pressing) the sides are hung from rods in the smoke oven by means of hooks, similar to those used for mild-cured sides. The first fires to be kindled are of the drying type in order to remove the surface moisture and to form a pellicle. From 2 to 4 days are required, during which time the dampers and louvers are kept open so as to maintain good circulation. When the sides are sufficiently dried, smoking fires are built and the air circulation reduced by partially closing the dampers and louvers. The length of this stage will depend on the type of product desired, and may be as long as 10 days for a really hard-dried smoked salmon with good keeping qualities. However, 4 to 6 days will suffice for the average markets. The temperature should not exceed 85 to 90° F

(29.4 to 32.2° C). Shrinkage in the smoking process may run as high as 50 per cent.

These hard-smoked sides may be packed for shipment and sold without further preparation. But more often they are cut into strips, chunks, or slices and packed in jars or cellophane bags for distribution to the tavern trade. Since this

(Photo R. K. Pedersen)

FIG. 19–4. Hard-smoked salmon smoked in controlled smokehouse.

product is fairly dry and somewhat salty, it keeps quite well without refrigeration. In humid climates the growth of molds must be guarded against by the use of adequate packaging materials.

Hard or Red Herring. The first step in the smoking process is brining or salting. In the United States this is always effected by placing the fish in butts, tanks, or vats filled with strong brine; but in Europe the fish are often simply mixed with dry salt. If the herring are caught at sea at a distance from the home port of the fishing vessel, they are salted on board the vessel soon after they are caught. When fresh herring intended for smoking are landed at the docks, they are taken to the salting sheds, where they are immediately put into salting vats partially filled with brine. Sufficient herring are placed in the vat to cover the bottom, and then about a half bushel of salt is scattered over them. Another layer of fish, from 1 to 2 barrels, is put in and a layer of salt, from 1 to 1½ bushels, thrown over them. The tank is then filled with fish and covered with 3 to 5 bushels of salt. Each tank holds about 4 hogsheads of fish and the quantity of salt used varies from 6 to 9 bushels, depending upon the condition of the fish and the weather. The fresher the fish, and the cooler the weather, the less salt required. The greater portion of salt is placed on or near the top of the fish so that in working down through the herring it will dissolve before it reaches the bottom of the vat.

Small fish are allowed to remain in the brine from 24 to 36 hours, while the

large ones are kept in the vat for about 48 hours, or until they are thoroughly "struck." The length of time which the fish remain in the vats depends to some extent upon the weather; the colder the weather, the longer they are left in the brine.

When properly salted the herring are dipped out of the vats by means of dip nets or "wash nets." As the fish are dipped out, they are usually washed in sea water or salt brine. After washing, or rinsing, they are laid on stringing tables and allowed to drain. They are then strung on thin sticks, about 3 feet 4 inches in length and ¾ inch in diameter. The stringers raise the left gill cover of the herring and insert the pointed end of the stick first through the gill slit and then through the mouth; at the same time the fish is shoved to the other end of the stick. Twenty-five to 35 herring are strung on each stick. A single person can string 500 to 1000 sticks a day.

The herring which have been strung on the sticks are washed by being dipped in a trough of sea water and hung on rectangular frames, called "herring horses." Each "herring horse" holds about 45 sticks, or 1 barrel of fish; when it has been filled, it is carried into the open air where the fish are drained and slightly dried. This preliminary drying hardens the gill covers, thus preventing the fish from falling off the sticks in the smokehouse. The length of time which the herring are dried depends chiefly on the weather. If it is foggy or rainy, the fish are drained for a few minutes, and are immediately placed in the smokehouse where they are dried. All the doors and windows are opened, and drying fires are kept going in order to dry the fish quickly.

Inasmuch as the herring are obtained in relatively small quantities and the business is usually conducted on a small scale, some time is required to fill a smokehouse. Even when the herring are obtained in large quantities, the smokehouses are filled by degrees to insure the thorough drying of the fish during the smoking process. If the house were completely filled, the atmosphere would become entirely saturated with moisture; and if the temperature should happen to fall, the condensing moisture might spoil the fish.

When the fish have been sufficiently dried outdoors, the "herring sticks" on which herring are hung are brought into the smokehouses and placed on scantlings (frames), which are just far enough apart so that both ends of the sticks rest on them. The sticks are placed far enough apart so that the herring do not touch each other. The lower part of the "bays" in the smokehouse is usually filled first. When 1 day's supply of herring has been placed in the smokehouse, the drying fires are kindled and the fish are dried for 12 to 15 hours. The fires are then allowed to go down, and the partially dried herring are shifted to a place nearer the top of the smokehouse. Another lot of fish is then placed in the lower part and the preliminary drying is repeated. Usually about 2 weeks' time is taken in filling an average-size smokehouse. After the smokehouse has been filled and all the herring have received a preliminary drying, the herring are given an additional smoking of about 3 weeks' duration.

Usually the fish are not taken from the smokehouse until they are to be packed or boned. If the packing is delayed some time after the smoking has been completed, the smokehouse is kept open during the day, and during damp weather fires are kindled to prevent the fish from becoming wet. When the herring are to be packed, they are removed to the packing house where they are sorted into

grades according to their size and fatness and packed in herring boxes. The principal grades of hard herring are "medium-scaled," "lengthwise," and "No. 1." The best grade is "medium-scaled," which is divided into two sizes, known as large and small-medium. Medium-scaled herring are packed crosswise in wooden boxes; a box of the large medium-scaled herring contains from 30 to 40 fish, and the boxes of the medium size average 45 to the box. "Lengthwise" herring are larger than medium-scaled and receive their name from being packed lengthwise of the box, which contains from 15 to 18 smoked fish. The "No. 1" herring are the smallest and least valuable, and are packed 60 to 75 to a box. Other grades of smoked hard herring less generally recognized are "tuck-tails" and "Magdalens."

In the preparation of boneless smoked herring the fish are dumped on wooden tables, and their heads, bellies, and tails are clipped off with scissors. The cut fish are taken to other tables where they are weighed. Women and girls then remove the skin and bones by hand; the faster workers can skin and bone 100 to 150 pounds of herring daily. The prepared herring are usually packed in wooden boxes lined with paper and are then ready for shipment. Some of the boneless fish are packed in jars and cellophane bags, in which form they are popular with certain consumers. One hundred pounds of smoked fish yield about 30 pounds of the boned. Smoked boneless herring are the most valuable smoked herring product.

Bloaters. Although smoked bloaters may be prepared from fresh herring which have had only a light preliminary brining, it is customary to use hard-salted round fish for this purpose. Only the larger sizes of herring are used, and preferably those having some milt and roe, so that a fuller effect will be evident after smoking. Either a brine or dry-salting process may be used for the preliminary curing. Because boxes may be used for shipping the dry-salted herring from the salting stations to the smokeries, it is usually more convenient and cheaper to use this method. The cured herring can be held for some time before smoking; but if the storage period is prolonged, it is advisable to use a cold room with the temperature just above freezing, 32° F (0° C).

As the herring are heavily salted, it is necessary to give them a long soaking in fresh water before smoking to remove the excess salt. The time of freshening will depend on length of storage and may be up to 48 hours. The soaking is done in large tanks or vats of running water and the herring should be stirred from time to time to secure uniform freshening.

The fish are shoveled out of the tanks with a wire scoop and onto a large table of convenient height for the "stringers." The "herring sticks" and method of stringing is quite similar to that used for hard or red herring. However, as the fish are larger, only from 15 to 20 can be placed on each stick. After draining on the "herring horses" or racks for a few hours, the sticks of herring are placed in the smoke oven in the same manner as described previously. However, the smokehouses used for bloaters are smaller and usually filled at one time. More uniform smoking results if only three or four tiers of herring are smoked simultaneously. If larger quantities are desired, it is advisable to fill the oven in stages to facilitate the drying.

With the drafts and ventilators open the drying fires are burned for 2 to 3 days until all surface moisture is removed and the skin of the fish is thoroughly dried. The air circulation is then reduced and smoking fires built for another 2 to

3 days. The total time required is from 4 to 6 days, depending largely on weather conditions; longer time is necessary when the atmosphere is damp. Temperatures should be maintained below 80° F (26.7° C); this is especially important if the herring are on the oily side.

After smoking, the bloaters are graded for size: medium, large, and extra large. Packing is done by count instead of by weight. Wooden boxes holding 25 or 50 fish are used, with the box sizes varying for the several grades. Smoked bloaters will keep for a limited time without refrigeration; but, since they are susceptible to mold growth, extended storage should be at temperatures below 32° F (0° C). In the United States the principal bloater markets are in the foreign sections of the larger cities.

Cold-Smoking (Light Salt Cure). Only fresh or frozen fish are used for this type of cure and just a light brining is used prior to smoking, mostly for flavoring purposes. There is some coagulation of the surface proteins from this preliminary brining, but the preservative effect is meager. It is therefore essential that the raw materials be of excellent quality and strictly fresh. The finished products are all highly perishable and storage must be under refrigeration below the freezing point.

Finnan Haddies. This process, which accounts for one of the major smoke industries in Europe, especially in Scotland, originated in Findon, Scotland. Haddock is, of course, the principal species smoked in this manner. Recently other species of the cod family, such as true cod and pollock, have been utilized. The process used in the United States is similar to that used in Europe, except that a slightly heavier cure results due to longer smoking and salting.

Only medium-sized or large fish are used. They are dressed when received from the vessels. The fish are split from the belly side along the backbone so that they will lay open in a single piece. The backbone is not removed. The split fish are washed well and scrubbed to remove the dark belly lining. Brining is light, 2 to 2½ hours in 60° Sal. brine being sufficient. In order to reduce the shrinkage and smoking time some curers dip the fish in a dye solution before smoking. The food dye, tartrazine, is commonly used and the solution made by adding 2 ounces of the dye powder to 10 gallons of water.

After draining, the fish are hung by their napes from special sticks, having projecting nails on 2 sides to hold the fish flattened out while being smoked. Three fish are usually suspended on each side of the stick. When they are placed in the smoke oven, drying fires are built with all ventilators open. In 6 to 8 hours the surface moisture is evaporated and a light pellicle has developed. The ventilators are then closed and the fish are subjected to smoking fires for an additional 6 to 8 hours. The temperature should be held below 90° F (32.2° C) to produce the best results.

Packing is usually in 15-pound boxes, with the fish being graded for size and the number per box being stenciled on the outside. Since both the brining and smoking are light, finnan haddies are highly perishable. Shipping and storage should be below 32° F (0° C).

Smoked Fillets. These are produced from a variety of fresh fish, large cod, haddock, pollock, ling cod, etc. being the most common. The process used is essentially the same in all cases.

The fish should be fresh and in good condition. Each fish is skinned and boned and cut into 2 fillets, which are then brined for 1½ to 2 hours in 50 to 60° Sal.

brine. The fillets are usually colored with tartrazine and hung over rods in the smokehouse where they are cured in exactly the same way as finnan haddie. In fact smoke fillets are utilized in the same manner. They are perishable, and if stored must be kept frozen.

Kippered Herring. For a long time a favorite food of the Scotch and English people, kippered herring have become increasingly popular in America and are now being prepared on both the Atlantic and Pacific Coasts.

Fresh and frozen herring of the larger sizes are preferable for kippering purposes. Fall or early winter-caught fish, which are neither too fat nor too lean, are the best. With a small knife the herring are split along the back from head to tail, with the belly remaining intact. The head and backbone are not removed. After the entrails and gills are cleaned out, the split fish are washed thoroughly, especially along the backbone, to remove blood, slime, and loose scales. Brining for 30 to 45 minutes in a 60° Sal. brine is sufficient to give a good flavor. After draining, the fish are hooked on special kipper sticks, and then placed in the smoke oven. A preliminary 6- to 8-hour period with drying fires, followed by smoking fires for about the same length of time, completes the cure. The temperature should be maintained below 85° F (29.4° C).

The shrinkage from the round weight will average about 40 per cent, but may run as high as 50 per cent in the case of small, lean herring. Flat wooden boxes, containing 10 pounds of the kippers, are used for shipping. Since kippered herring are a highly perishable product, they must be used within a few days after preparation. However, by freezing they can be successfully shipped and stored for extended periods.

Hot-Smoking or Barbecuing. *Kippered Salmon.* The hot-smoking or kippering of salmon has had its greatest development in the Pacific Northwest, where this product is a staple article in nearly every butcher-shop and delicatessen store. In recent years its use has spread to other sections of the country. Smokers in many of the larger cities, especially in the Midwest and East, now cure kippered salmon daily. On the Pacific Coast it is customary to use fresh fish during the active fishing season and frozen fish the remainder of the year. In other places the frozen stock is utilized on a year-round basis. Although all species of salmon may be used, the most suitable one, from the standpoint of size and quality, is the king or chinook, with the chum or fall as second choice. It is quite possible that during the inception of this industry the red king salmon was used; but, as the price of this variety increased, attention was turned to the utilization of the white king, which commanded a much lower price. In order to obtain the same external appearance it became necessary to dip the pieces of white king in a red coloring solution. However, there is no appreciable difference so far as quality is concerned. Some claim that the white variety is fatter and more tasty than the red, but these factors may be more dependent on place and time of capture than on color.

Frozen fish must, of course, be thawed out before use; this is usually done in tanks of running water and takes from 8 to 15 hours, depending on the size of the fish and temperature of the water. After removal of the fins the fish are split in half and the backbones are removed, thus making fillets. This splitting operation is quite similar to that described in the section on mild-cured salmon. The backbone may not be removed when some of the smaller species of salmon are utilized. The sides are thoroughly cleaned and washed, then cut into approximately

1-pound chunks after smoking. Proper flavoring is accomplished by soaking the salmon in 100° Sal. brine for about 2 hours, or in 50 to 60° brine for approximately 3 hours. The coloring is done by dipping the brined chunks of salmon for 15 to 30 seconds in a tub containing a dye solution made by dissolving 3 to 4 ounces of certified Orange I food color in 20 gallons of fresh water. This amount of solution will suffice for 1000 to 1500 pounds of fish. The colored pieces are then laid skin side down on special wire screens. Care must be taken that the pieces do not touch one another. The filled screens are placed in the smoke oven and the smoking process started.

With all dampers and ventilators open to secure good air circulation, drying fires are first applied for a period of 8 to 12 hours. The initial temperature is around 85 to 90° F (29.4 to 32.2° C), but this is gradually increased to 110° F (43.3° C) and finally to 120° F (48.9° C). By this time the pieces will be well dried and a firm pellicle will have formed on all cut surfaces. Unless this preliminary drying and pellicle formation are properly accomplished, the finished pieces are apt to crack, resulting in a loss of juices and in poor appearance. The air circulation is then reduced by partial closure of the dampers and ventilators. Cooking fires are kindled and the temperature slowly built up to the barbecuing point of around 170 to 180° F (76.7 to 82.2° C). Although some smokers employ temperatures up to 200° F (93.3° C), a better, brighter color results and less shrinkage occurs at lower temperatures. The time of barbecuing varies from 2 to 4 hours, depending upon the temperature. The shrinkage in the entire smoking operation is about 15 per cent for large fat chunks and as much as 25 per cent for small lean pieces.

After thorough cooling, the pieces of kippered salmon are wrapped in cellophane and packed in boxes holding 5 or 10 pounds net weight. This product is very susceptible to mold growth in humid climates and will keep only from 3 to 5 days at room temperature. Freezing temperatures are recommended for shipping and storage.

Barbecued Sablefish (*Kippered Black Cod*). This is another smoked fish product that had its original development in the Pacific Northwest. Its popularity has been increasing each year, and it is now being smoked in California and in all the larger cities of the Midwest and East. A rich oily fish, it is especially relished by the Jewish trade.

Barbecued sablefish prepared from frozen stock is inclined to be firmer and less watery than that from fresh fish. As a result nearly all smokers now use only frozen fish for their raw material. The entire barbecuing process is essentially the same as that used in smoking kippered salmon. Due to the oily nature of the fish, cooking temperatures slightly lower than that used for salmon may be employed with success. The backbone is customarily not removed. The shrinkage in the smoke oven is somewhat less (running only 10 to 15 per cent) than with salmon. As with salmon freezing temperatures are recommended for shipping and storage.

Barbecued (*Kippered*) *Ling Cod, Shad, Sturgeon, Etc.* The same hot-smoking process used for salmon and sablefish has also been applied by Pacific Coast smokers to a number of other fish, such as albacore, barracuda, ling cod, shad, sturgeon, soup-fin, and other species of shark. Of these, ling cod, shad, and sturgeon are most commonly used, but the volume has never been of any great

significance. Although the manner of butchering and cutting into chunks and the time of brining vary somewhat with the species, the smoking operation itself is essentially as described previously for kippering salmon.

In the midwestern and eastern states similar methods of preliminary preparation and of hot-smoking are in use for such species as catfish, lake trout, sturgeon, swordfish, and whitefish.

Hot-Smoked Lake Herring and Other Small Fish. Many of the smaller species of fish are given a short, hot smoke to enhance their flavor and thus give them greater sales appeal. The cisco and other varieties of lake herring are widely used in the Great Lakes and surrounding areas. On the East Coast small quantities of the following fish are hot-smoked: alewives, butterfish, eels, flounder, mackerel, and sea herring (usually called buckling after smoking). Lesser amounts of anchovies, eulachon (Columbia River smelt), herring, and sardines are prepared by hot-smoking methods on the Pacific Coast.

Preliminary preparation varies somewhat according to locality, and also depends on market demands. Some may be left in the round; others are gibbed, or headed and gibbed. Brining is usually very light, time and concentration depending upon the size of the fish and the amount of preliminary dressing. A 60° Sal. brine solution may be used, and the time of brining may range between 15 and 45 minutes.

After brining, the fish are either spread out on oiled wire screens or strung on rods before being placed in the smokehouse. Since these fish are relatively small and retain their skin, the preliminary drying can be accomplished in from 4 to 6 hours, after which time the ventilators are closed and the temperature is allowed to rise to around 150° F (65.6° C). Hot-smoking for 2 to 3 hours at this temperature is sufficient to barbecue thoroughly and cure these products. All of them are perishable and, unless consumed within a few days, should be held in freezing storage.

Oriental Smoking Methods. *Herring-Type Fishes.* All along the coastal areas and throughout the island groups of the Orient and East Indies herring-like species of fish are smoked in a unique fashion. The method is Chinese in origin and is usually carried out by Chinese. The process varies somewhat from one place to another, but in general the small fish are first washed and then placed in a vat of boiling salt water in which they are cooked for various lengths of time, depending upon the size of the fish and the concentration of the salt solution. The fish are next spread out on flakes and dried in the sun for 1 or 2 hours. This removes surface moisture. The dried fish are now ready for smoking and are placed in small, round bamboo baskets, so constructed as to allow circulation through the bottom. The fish are placed one layer deep, either with head down and tail up or on their bellies and at a slight angle so that the rows overlap. The individual baskets are then placed over a round opening in the top of a long concrete furnace which contains a series of similar openings. Several baskets are piled one above the other and a tightly woven cover is placed over the top one. Smoke is produced from a smouldering hardwood sawdust fire. Smoking only takes from 4 to 6 hours, and during this time the position of the baskets or trays is changed. The fish are carried to the markets in these trays and sold by the tray full. However, if the product is being prepared for export, it is given a longer smoke and is packed in large wooden boxes holding up to 60 kilos.

Smoked Bonito Sticks. Another distinctive method which is utilized principally by the Japanese is the production of bonito sticks (Smith, 1947). The fresh bonito are headed, eviscerated, and split into fillets; if the fillets are large, they may again be split. The strips are then placed on trays and boiled for 1 to 2 hours. The temperature is raised slowly so as to prevent splitting. After cooking, the skin and bones are removed and any cracks in the flesh are filled with a fish paste so that the original shape is maintained. The fish are next dried on trays in large ovens over a wood fire which both dries and smokes the strips. This process is taken slowly so as to dry the fish thoroughly. When the process is complete, the pieces are dark brown in color and very hard. A further step is the removal of fat, which is accomplished by a mildew process. The sticks are allowed to stand in a warm, damp room until covered with mold. The latter is then scraped off and the pieces are sterilized. A very hard, durable product which keeps remarkably well is the result of this process. The sticks, which are extensively used in preparing soups and broths, are so hard that shavings must be pared off for use.

Smoke Curing Prior to Canning. In recent years there has been a noticeable increase in the canning of certain fish and shellfish which have been given a preliminary smoke cure. This procedure gives the canned product additional flavor, enhances the color, and in some cases improves the texture. Subsequent storage tends to intensify the smoke flavor and color. For this reason the fish should not be over smoked. Canned smoked products may be prepared from fresh and frozen fish or from salt-cured fish, such as salt herring and mild-cured and hard-cured salmon. However, two quite distinct types are produced depending upon the kind of material used. All these that are prepared from salt-cured fish are not heat-processed after sealing in the cans. The tin container merely serves as a suitable package for marketing purposes. In the processed type the fresh or frozen fish is subjected to a preliminary smoking, followed by heat-processing or sterilization of the canned product.

Non-Processed Products. As previously mentioned, smoked mild-cured king salmon sides may be sliced and packed in 1- and 5-pound tin cans. Some packers add a small quantity of vegetable oil to each can. Since this item is highly perishable, it must be shipped and stored under refrigeration preferably just above the freezing point.

Another excellent article prepared on the Pacific Coast is canned hard-smoked salmon. Following the usual procedure of hard-smoking the sides of salmon are cut into can-length sticks or into slices and then packed in tin containers of various sizes. Oil may or may not be added. While all 5 species may be used, the red and silver salmon, because of their better color, produce the most attractive packs. The keeping quality depends entirely on the amount of moisture removed by the smoking process. The dryer the fish the longer it will keep without refrigeration. However, for extended periods cold storage is recommended.

In Norway and other Northern European countries a variety of non-processed products are prepared from cold-smoked fish, such as salmon, herring, mackerel, pollock, etc. The customary procedure is to smoke the fish until firm and reasonably dry. After removal of the skin and bones the fish are cut into thin slices. Packing is usually in small rectangular tin containers, similar to a ¼-size sardine can. Vegetable oil is generally added to fill the container before sealing. Extended storage should, of course, be under refrigeration just above the freezing point.

Processed Products. The preliminary smoking methods employed for these processed products may again be classified under the headings of cold-smoking and hot-smoking. The application of a cold-smoke is strictly for flavor purposes, while in hot-smoking there is, in addition to the flavoring, the drying effect of the heat. Sufficient moisture is removed to make the finished product much firmer in texture and more attractive in appearance.

In cold-smoking salmon before canning the fish are split into halves and the backbone removed (fillets). The skin is left on to facilitate hanging in the smoke oven. Brining is usually dispensed with as a more uniform salting can be attained by adding a measured amount of salt to each can. Time of smoking is from 12 to 16 hours, with the temperature being held below 85° F (29.4° C). After smoking, the skin is removed and the sides cut into can-length pieces. These are then packed in ½-pound salmon cans, usually without the addition of oil. The rest of the procedure follows the regular canned salmon process. Sturgeon and shad are prepared in a similar manner. However, with shad the backbone and skin are not generally removed. In the preparation of smoked Maine sardines the small herring are subjected to a steaming operation to remove the excess moisture before cold-smoking. The new process of electrodeposition of the smoke flavor is now being carried out after the fish have been packed in the cans.

Canned barbecued or kippered salmon is prepared from fresh and frozen fish. All 5 species of Pacific salmon have been used, but by far the best product is made from the king or chinook. Cleaning, splitting, and cutting follows the technique for the regular kippered salmon. However, care should be taken to cut the chunks so that they will be can-length after smoking. Some operators cut the sides into long strips for the hot-smoking operation. After cooling, these strips can then be cut into proper can-length. Time and temperature of the smoking process is essentially as described under kippered salmon. Some operators prefer brining before smoking, while others add the salt to each can. A small quantity of vegetable oil is usually added to each can after packing. Standard canned salmon procedure completes the process. Sturgeon, shad, black cod, and other species of fish may be canned in a similar manner.

Undoubtedly the most popular canned hot-smoked fish product is the Norwegian sardine, which has found world-wide acceptance. The top grade is prepared from the brisling or sprat, a dwarf member of the herring family; for the second grade, young of the sea herring (sild) are used. The method of preparation is the same in either case. If the fish contain feed, they are impounded for a day or so to clean out the stomach and intestinal tract. Upon arrival at the plant they are thoroughly washed to remove slime and loose scales. Without butchering or cleaning of any sort the fish are brined for 15 to 20 minutes in 100° Sal. brine. Following another wash in fresh water they are strung on wire rods inserted through their heads. These rods are then placed on special frames for convenience in handling. The fish are then subjected to a quick hot smoke in the smoke ovens for about an hour. When thoroughly cooled the heads are trimmed off and the fish are packed in ¼-pound, rectangular tin containers. After filling the cans with oil the usual canning procedure follows. "Kipper-snacks," which are smoked fillets of large herring, are prepared in a somewhat similar manner, usually without the addition of oil.

On the Pacific Coast a modified Norwegian method has been employed on a limited scale to pack a species of anchovies which is found in abundance off the coast of Canada and the United States. Since the size and quality of this fish is similar to the Norwegian brisling, there is every promise of a future industry.

Oysters, clams, shrimp, and crab legs have all been smoked and canned successfully. These specialty products are always in demand for use as hors d'oeuvres. Oysters may be prepared by first being steamed open to loosen the meats for easy removal. This precooking firms the meat and improves the texture. The meats are brined for only 5 minutes in a 60° Sal. solution, after which they are spread out on oiled wire-screen trays for handling in the smoke oven. Two to 3 hours' smoking, with a gradual increase in temperature from 110 to 140° F (43.3 to 60° C) is sufficient to produce the desirable light tan color and delicate smoke flavor. Packing is usually in ¼-pound, round or rectangular cans. Small glass jars may also be used. After the containers are filled with oil, they are sealed and heat-processed in the usual manner. Handling of the other types of shellfish is essentially the same, some kind of precooking being necessary before the smoking operation.

Curing Fish by Drying and Dehydration

Introduction

Although in ordinary usage the words *drying* and *dehydration* may be considered synonymous, when speaking of fish it is customary to make a slight distinction between them. The term *drying* is applied to those processes in which the moisture is removed by exposure to natural currents of air and the humidity is regulated by climatic conditions. Dehydration, on the other hand, is carried out in a man-made apparatus in which the air currents and heat are produced artificially and the relative humidities are under control.

Drying in the open air is without doubt the most ancient method of preserving food. Aboriginal man must have learned early in his existence how to hang and dry his surplus fish in the open air; perhaps he made use of some rocky point jutting out into the ocean so as to take advantage of the prevailing winds. Some of the methods practiced today are probably not unlike the primitive methods. Natural drying of fishery products has been employed to a certain extent in all fish-producing countries, and in the United States limited quantities are still being prepared.

It would seem logical that sizable fish-drying industries would have developed in tropical countries; however, this was not the case, except in certain island areas where prevailing winds were steady and uniform. Conditions such as these are found in the southern Philippines and parts of the East Indies, where salted and unsalted dried fish are a major item of diet. Nevertheless, most tropical countries do not produce large quantities of dried fish. The abundance of fresh food at all seasons of the year may have made it unnecessary to learn how to preserve the catches; or heat and high humidity may have caused such rapid spoilage that fish-drying was impracticable. More progress has been made in the temperate zones, and the greatest amount of dried fish has always been produced in countries far from the equator. There is extensive fish-drying in the northern part of Norway beyond the Arctic Circle. The Japanese dry a greater quantity and variety of fish

than any other country as dried fish products are a staple article of diet throughout the Orient.

Although a greater percentage of fish is preserved throughout the world by natural air-drying, this traditional method does not yield a first-class product. Research on a suitable method for artificial dehydration has been carried out for the past half century, and it has only been in recent years that fairly effective processes have been developed. Before discussing dehydration (artificial drying) in detail the important natural drying procedures will be considered.

Natural Air-Drying. The advantage of this method of fish preservation is that no specialized equipment is necessary and it may be accomplished under primitive conditions. However, exposure to wind and weather is a relatively slow procedure and results in much loss through spoilage, in lack of uniformity in the final product, and in the development of characteristic "cured" flavors which, although highly acceptable to some people, may not continue to be accepted by future generations, especially in urban centers.

Most drying processes result in a product with a moisture content of 5 per cent or less, at which point practically all growth of microorganisms and enzymic action is stopped. However, care must be exercised in the storage of all dried fish products. Surface dampness due to high humidities invites mold growth and subsequent spoilage. Oxidation of the fish oils, with its resultant rancid flavor, is hastened by exposure to the sun and warm temperatures. Therefore, in order to lengthen the storage period dried fish should be stored in a cool, dry place where there is a minimum of air circulation.

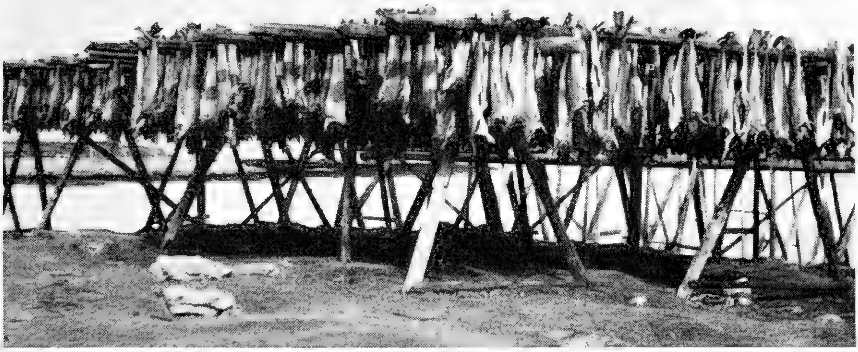
Stockfish. For over a thousand years northern Norway has been the center for curing dried codfish, or stockfish as it is known to the trade. This staple article of commerce is marketed throughout Europe, especially in Italy, Spain, Holland, Sweden, and Denmark. Lesser quantities are sold in other parts of the world, including the United States, where there are Scandinavian and Latin settlements. Although minor amounts have been cured from time to time in Alaska and Japan, Norway has firmly maintained its supremacy in the production of stockfish. That part of Norway beyond the Arctic Circle is an especially favored location for the natural drying of fish products because of its clear, cool weather and prevailing westerly winds.

The waters surrounding this area have an unusually prolific and varied number of food fish. Common cod, or true cod as it is sometimes called, occurs in great abundance during the early part of each year in the inshore waters close to the curing ports. This species is the principal one used for preparing stockfish, but all other members of the cod and closely related families can be and are cured by drying in the open air. Because of the proximity of the fishing grounds the Norwegian curer is always able to start with a strictly fresh fish, a decided advantage in any dry-curing process.

As the fish are brought ashore, the butchering and preliminary preparation commence. The belly is opened from just behind the pectoral fins to just beyond the anal opening. The isthmus must remain intact. The head is then removed by a cut made just in front of the pectoral girdle (collarbone) from the ventral to the dorsal side. If the fish is large, it may be split in two as far as the tail. In these fish, called "rotskjaer," about two-thirds of the backbone is also removed. The unsplit fish are known as "rundfisk"; after heading they are passed to a gutter

who removes the roe and the liver which are saved and the entrails which are discarded. The air-bladder should remain in the fish. After butchering, the fish are thrown into a vat of sea water for washing.

Following a brief draining period the fish are ready to be hung outside on drying racks. Each rack consists of a series of poles supported by scaffolds, some of them 8 or 9 feet above the ground. A number of these racks may be located on some rocky promontory. In hanging, two of the "rundfisk" are tied together at



(*Photo by C. L. Anderson*)

Fig. 19–5. Stockfish on the drying racks, Northern Norway.

the tails by a piece of cord, than draped over a pole, with one fish on each side. The "rotskjaer" (splitfish) are likewise suspended from a pole, with one split side on each side.

Placing the racks so that the prevailing winds will blow through the rows of fish permits faster and more uniform drying. In addition it is necessary to turn the fish from time to time to prevent formation of soft spots where two pieces may have accidentally touched. Until the skin becomes well-hardened and a tough pellicle has formed on the cut surfaces, extreme care must be exercised in drying.

Drying continues for several months, or until the thicker dorsal portion cannot be pressed in with the fingers. The highest quality is that in which the vertebrae show through; this characteristic is prized by southern Europeans, who are the best customers for the product. The popular "lutefisk" of the Scandinavians is prepared from this same stockfish.

Dried Salmon. Along the Yukon, Kuskokwim, and other rivers of the interior of Alaska large quantities of salmon are air-dried during the summer months. The annual production will vary from about ½ million to over 2 million pounds, with a value of from 4 to 8 cents per pound. The chum or dog salmon constitutes the bulk of production, but minor quantities of the other species of salmon are also cured.

The process employed is quite similar to that used for curing stockfish. After cleaning and splitting into halves the sides of salmon are hung over poles supported on trusses several feet above the ground. These drying racks are built in favorable locations along river banks where there are prevailing winds. The

curing process continues for several months until the flesh becomes so firm that it cannot be depressed with the fingers. During the long Arctic winters this dried salmon constitutes an important part of the protein portion of the diet of both the native and his dogs.

Miscellaneous Dried Products. Throughout the Orient the drying of fish products comprises a sizable section of the fishing industries, and dried fish is a staple item in the diet of the people of this region. Although there are many species of fish

(*Photo by C. L. Anderson*)

FIG. 19–6. Japanese drying sardines at San Pedro, California.

and the mechanics of handling the products vary greatly, the essential curing process so thoroughly removes the moisture by drying in the open air that the product will keep over an extended period of time. The Japanese dry such fish as cod, herring, mackerel, sardines, albacore, and tuna.

Dehydration or Artificial Drying. *Principles of Dehydration.* The basic principle involved in drying fish, whether by natural or artificial means, is the reduction of the moisture content to such an extent that decomposition by both bacterial putrefaction and enzymic autolysis is stopped, or at least sufficiently inhibited to insure reasonable keeping qualities. In natural drying the curing proceeds so slowly in most cases that a certain amount of decomposition does occur before the desired reduction in water content is reached. This is evidenced by peculiar "cured" odors and flavors. These are not considered objectionable by those accustomed to using such dried items in their diet; in fact they may even be relished. However, to the average person they are so objectionable that such products are seldom used. Another objection to natural air-dried fish is that its character is so changed in the curing process that it absorbs water very slowly in soaking and upon reconstitution never attains the original gelatinous character of fresh fish. Upon storage further undesirable changes occur due to certain physical and chemical alterations in the flesh and oil of the fish (Tarr, 1943).

Dehydration, then, consists of the application of artificial drying in such a manner that these objectionable features are overcome. The drying process is speeded up by controlled temperature, humidity, and air velocity. There have been many attempts during the past half century to prepare dehydrated fish prod-

ucts that would be economically feasible on a commercial scale. Because of the military need for products that would keep well and at the same time require a minimum of space researchers were assigned during both world wars to study the problems of dehydration. While the primary demand was military, it was hoped that a suitable product could be developed that would be acceptable to the domestic markets in normal times.

Much progress has been made and many problems solved. Information is now available on the proper pretreatment of the raw material. Correct temperature and humidity in relation to the time element have been worked out, and more is known about how to pack and store the finished products. However, even in the light of the most recent experiments successful storage is difficult to attain and the cost of the dehydrated product is almost too high for commercial production for the domestic market (Stansby, 1945).

Dehydration Processes. A convenient definition of dehydration as applied to fish as well as other foods is "drying in an atmosphere of controlled temperature and humidity to a definite end product in a given time" (Cutting and Reay, 1944). In order to accomplish this a variety of drying methods have been used, such as vacuum-drying, vacuum-drying combined with freezing temperatures, and spray-drying. More orthodox methods, including cabinet driers or tunnel driers, of both the conveyor and stationary type, have also been used. The more elaborate processes of drying, such as *in vacuo,* have been found impractical for fish products. Since fish drying can be carried out under a fairly wide range of conditions, complicated processes and equipment are not so essential as with some other types of food products. The most important factors were found to be preliminary preparation of the raw material and storage of the finished product.

In all the processes so far devised it has been demonstrated that the fish must be precooked in order to obtain a satisfactory rate of drying. In addition it was learned that the removal of moisture could be accelerated by mincing or grinding the precooked material. According to Stansby (1945) the dehydration of raw fish proceeded at a rate of only one-third that of cooked fish. In addition rehydration was slower and only half as much water was absorbed. Canadian investigators (Young and Sidaway, 1943) recommend a further step in preliminary preparation. After cooking, the fish is skinned and boned; while the flesh is still warm, it is pressed at approximately 100 pounds per square inch to remove the expressible oil and water. The pressed cake is then ground or minced before spreading on screens for drying. It appears that this extra step not only speeds up the dehydration process, but aids materially in assuring satisfactory keeping qualities. The expressed oil and water, which contains some dissolved protein matter, represents a nutritional loss unless recovered and utilized as a by-product.

Processes for precooking are variable and range from 22 to 30 minutes at 212° F (100° C) to 7 to 10 minutes at 5- to 10-pounds pressure. The temperatures to be used in the dehydration process also cover a wide range. It is generally agreed that the temperature should start high and be gradually reduced toward the end of the drying process. As the product becomes more concentrated, a high temperature in the final stages would scorch and darken it. Temperatures as high as 185° F (85° C) to 205° F (96.1° C) have been shown to do no harm in the initial stages. The final drying should, however, be carried out in temperatures ranging from 145° F (62.8° C) to 158° F (70° C). Although the relative hu-

midity should be kept low, it may vary between 10 and 40 per cent, the optimum being in the neighborhood of 20 per cent. A low relative humidity coupled with high initial drying temperatures is instrumental in maintaining a high rate of drying. With conditions such as these dehydration may be accomplished in around 4 to 5 hours, and the moisture content should be reduced well below 5 per cent.

Many species have been dehydrated, both in the United States and Canada, to yield a palatable product. Among these are angler fish, raja fish, sea robins, puffers, croakers, sea trout, whiting, Atlantic cod, Pacific gray cod, ling cod, herring, red snapper, halibut, pilchard, dogfish, Pacific mackerel, petrale sole, king salmon, coho salmon, chum salmon, and Pacific squid.

Immediately after dehydration the quality of the product is high, but upon subsequent storage certain changes occur which affect the texture, flavor, and appearance. These changes are quickened when the humidity is high or when storage is at high temperatures. Some investigators (Cutting and Reay, 1944) recommend that all dehydrated products be hermetically sealed in an atmosphere of nitrogen. Their research has indicated that storage time up to 2 years under normal temperatures may be obtained when packed in this manner. If not stored properly the product becomes rancid. Even the so-called non-oily varieties are affected; as moisture is removed, the percentage of oil to protein rises and the product becomes oily. Moreover, exposure to ordinary atmospheric conditions results in other rapid changes: the flesh darkens, becomes tough, and has a burnt flavor and odor.

Nutritionally speaking, the product is very good and recent research (Martenik and Jacobs, 1943) has indicated that on the species studied (cod, whiting, mullet, carp) neither the nutritive value nor the digestibility of the proteins was adversely affected. Most of the losses of vitamins B_1 and B_2 were in the precook process and could be recovered at least partially from the stickwater.

Rehydration is accomplished rapidly. The use of cold water is recommended and most species take less than 30 minutes to reconstitute. Four to 6 parts of water are used to each part of dehydrated fish and the resultant product has the color and texture of minced, cooked fish. The rehydrated fish is suitable for use in any recipe calling for flaked fish (i.e., fish balls, fish salads, fish loaves, etc.).

Pressfish. A recent innovation on dehydration is a method introduced in Norway which produces from cod something known as "pressfisk." Hamm describes the method as follows:

"The fish are first cleaned and split, the bones and skin are removed, and the flesh is laid flat on an aluminum sheet about 8 feet long by 4 feet wide. A second aluminum sheet is placed over the fish on the first sheet. Several of these 'sandwiches' so obtained are placed in the vacuum dehydrator.

"The dehydrator has a series of hollow plates, similar to a 'Birdseye' freezer, and one 'sandwich' is placed between each pair of opposing surfaces of the hollow plates. The plates are then pressed together by a hydraulic jack, the dehydrator is shut and evacuated to an internal pressure of about 25 millimeters of mercury, and hot water at 194° F (90° C) is circulated through the hollow plates. The heat passes readily from the hollow plates through the aluminum plates to the fish. After about 6 hours the flattened fillets are sufficiently dehydrated. They are then removed from the aluminum sheets and stacked in a dry room for a few days to allow equalization of the moisture content. Then 15-inch squares are cut from the fillets and fitted in layers into a deep, closely fitting receptacle of a hydraulic press.

"The fish are pressed twice: first rapidly at pressure of about 5,000 pounds per square inch, next in a second press for about one-half hour at a somewhat higher pressure. The final block produced is approximately 15 inches square by 10 inches high. This is cut by a handsaw into package-sized pieces approximately $5 \times 5\frac{1}{2} \times 1$ inches. The final product contains about 10 per cent moisture and is said to absorb one and one-half times its weight of water on being soaked several hours."

The initial production has been cod, and it is expected that other species such as pollock, saithe, and haddock will be utilized in this method. Pressfish is expected to compete with dry salted fish in the latter's markets, and might conceivably develop special markets in those areas needing a concentrated protein food and where storage conditions may be adverse.

REFERENCES

Fish Smoking

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

Anderson, C. L., and Pedersen, R. K., "The Smoke-Curing of Fish and the Application of a Controlled Method to the Process," *State of Washington, Dept. Fisheries, Tech. Rept.*, **1** (1947).

Anon., "Manufactured Fishery Products," U. S. Fish and Wildlife Service, *Commercial Fisheries Statistics*, 434 (1945).

Anon., "Herring and Allied Species, 1920–48," Washington, Food and Agriculture Organization of the United Nations, 1949.

Clague, J. A., "The Marketing and Processing of Fish in the Philippines," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **10**, No. 8, 1–16 (1948).

Cobb, J. N., "Pacific Salmon Fisheries," U. S. Bureau of Fisheries *Doc.*, **902** (1921).

Cooper, D. LeB., and Linton, E. P., "The Smoke-Curing of Fresh Fillets," Fisheries Research Board Canada, *Prog. Repts., Atlantic Stations*, **12**, Pts. 1 and 2 (1934).

Cutting, C. L., "Engineering Problems of the Smoke-Curing of Fish," *Chem. and Indus.*, **61**, 365–368 (1942).

Griffiths, F. P., and Lemon, J. M., "Studies on the Smoking of Haddock," U. S. Bureau of Fisheries, *Investigational Rept.*, **1**, No. 20 (1934).

Hamm, W. S., and Rust, W. A., "The Electrostatic Smoking of Sardines," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **9**, No. 2, 1–4 (1947).

Hess, Ernest, "The Bactericidal Action of Smoke," *J. Bact.*, **15**, 33–45 (1928).

Hofgaard, C., "Norway—Fisheries and Fish Processing," Oslo, Norges Eksportråd, 1940.

Jarvis, N. D., "Mild-Curing, Pickling, Dry-Salting, and Smoking Salmon," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **60** (1944).

Jarvis, N. D., "Curing of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.* **18** (1950).

Lemon, J. M., "Controlled Smoking," *Fishing Gazette*, **49**, No. 8, 12, 14 (1932).

Linton, C. P., and French, H. V., "Factors Affecting Deposition of Smoke Constituents on Fish," *J. Biol. Bd. Can.*, **6**, 338–348 (1945).

Mulliken, F. G., "The Land of Smoked and Boneless Herring," *Fishing Gazette*, **39**, No. 2, 13–16 (1922).

Shewan, J. M., "Some of the Principles Involved in the Smoke-Curing of Fish," *Chemistry and Industry*, **64**, 98–101 (1945).

Sidaway, E. P., "Comparison of Some British Columbia Softwoods for Smoking Fish," Fisheries Research Board Canada, *Prog. Repts., Pacific Stations*, **59** (1944).

Smith, R. O., "Survey of the Fisheries of the Former Japanese Mandated Islands," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **273** (1947).

Stansby, M. E., and Griffiths, F. P., "Preparation and Keeping Quality of Lightly Smoked Mackerel," U. S. Fish and Wildlife Service, *Research Rept.,* **6** (1943).

Takahashi, E., and Masuda, Y., "Antioxygenic Properties of Smoked-Herring Oil," *Agr. Chem. Soc. Japan J.,* **14,** 19–27 (1938).

Drying and Dehydration

Anderson, A. W., and Powers, E. A., "Fishing Statistics of the United States for 1945," U. S. Fish and Wildlife Service, *Statistical Digest,* **18** (1949).

Cutting, C. L., and Reay, G. A., "The Dehydration of Fish," *Chem. and Indus.,* **63,** 47 (1944).

Hamm, W. S., "Some Observations on Fish Processing in Norway," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **9,** No. 5, 10–17 (1947).

Martenik, W. A., and Jacobs, B., "The Nutritive Value of the Protein of Some Dehydrated Fishery Products," U. S. Fish and Wildlife Service, *Fishery Market News,* **5,** No. 8, 12 (1943).

Stansby, M. E., "Dehydration of Fishery Products," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **120** (1945).

Tarr, H. L. A., "Changes in Moisture, Micro-Organisms and Volatile Bases in Dehydrated Fish During Processing and Storage," Fishery Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **57,** 16 (1943).

Young, O. C., and Sidaway, E. P., "The Dehydration of Fish," Fishery Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **56,** 7 (1943).

CHAPTER 20

Canning of Fish and Fish Products

Introduction

Processing perishable foods which have been hermetically sealed in a container, as practiced in canning, is a comparatively recent development. The discovery of this method is generally attributed to a Frenchman, Nicholas Appert, who developed it about 1795. This method of food preservation retains to a large extent the original flavor of the food. This is one of its principal advantages over the more ancient methods of preservation, such as drying, salting, and cool storage. Another important advantage is that it can be easily transported and kept in any climate without appreciable deterioration. Canned foods are generally considered to correspond closely to and have all of the advantages of fresh foods, prepared and cooked in the home.

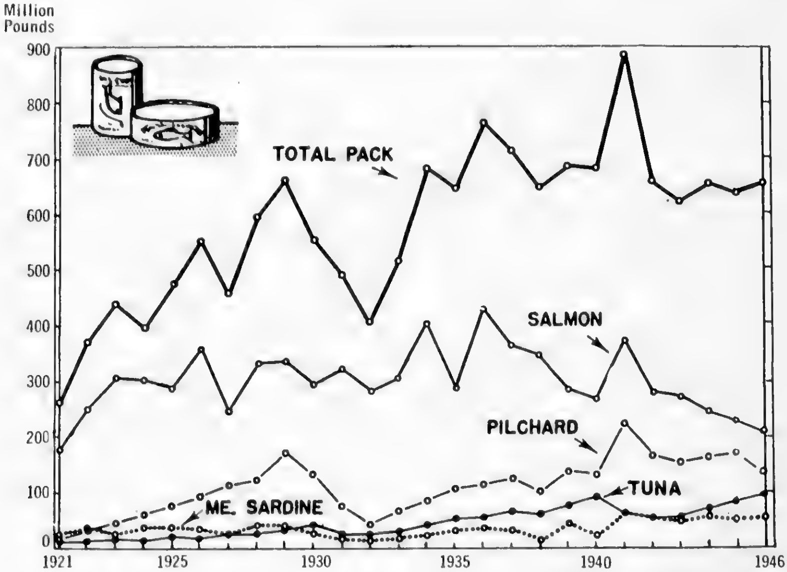
It is generally believed that fish were first canned in the United States about 1820. Lobster and other seafood were first canned in New York City by Thomas Kensett and Ezra Daggett, who were partners in the enterprise. About the same time, William Underwood established a plant in which lobster and fruits were canned in glass containers. This plant was located in Boston, Massachusetts, and is still in existence under the name of Wm. Underwood and Sons. It is the oldest canning firm in the United States. Canning of oysters and other seafood spread to Baltimore, Maryland, about 1835, and the experimental canning of herring as sardines was begun in Eastport, Maine, about 1840.

Salmon canning on the Pacific Coast was first attempted on the Sacramento River about 1860. The establishment of this first salmon cannery is attributed to William and George Hume and A. S. Hapgood. Although the first year of operation was successful, it is understood that the second season's pack resulted in failure. The plant and equipment were moved to a new location about 40 miles above the mouth of the Columbia River. Salmon canning spread rapidly northward from this point, and today extends as far as the Yukon River in Alaska. The canning of sardines and tuna in southern California began in the late 1890's.

The canning of the following varieties of fish and fish products has reached commercial importance in the United States: salmon, tuna, sardines, shad, herring, mackerel, cod, haddock, alewives, and roe. At present the salmon-canning industry is the most important fish-canning industry in America. It is located on the Pacific Coast from Monterey Bay in California to the Yukon River in Alaska. Sardines are canned along the entire coast of Maine and in California from Monterey to San Diego. The American tuna industry was also situated in southern California from Monterey to San Diego, but tuna are now canned as far north as British Columbia.

Sardines, mackerel, herring, anchovies, roe, and tuna are canned in various ways

in several European countries, while salmon and swordfish are canned in Japan and along the coast of Asia. Canada contributes very largely to the production of canned salmon.



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 20–1. The production of canned fishery products, fish scrap and meal, and fish oil was considerably below normal in 1946. Preliminary data indicate that about 657 million pounds of fish and shellfish were canned during the year compared with 646 million pounds in 1945 and a 1935–39 average of 690 million pounds. The production of fish meal amounted to about 186,000 tons. About 20,000,000 gallons of fish and fish liver oils were manufactured in 1946 compared with 24,501,852 gallons in the previous year and a 1935–39 average of 35.7 million gallons.

Outline of Canning Methods

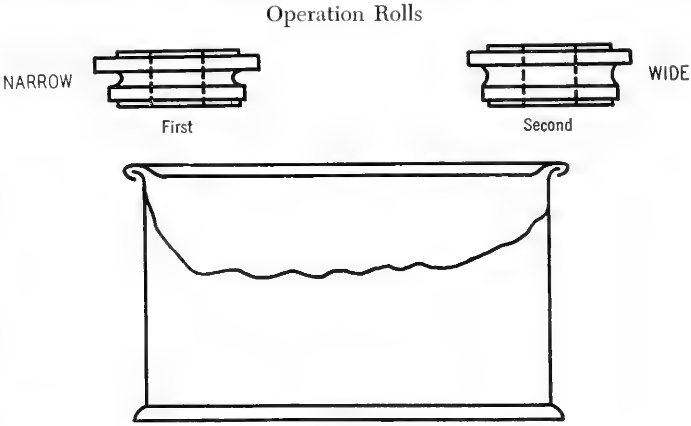
The important steps in the canning of fish and the purpose of each are briefly described below. The procedure necessarily varies considerably with different fish and with different products of the same fish. A more detailed description of the methods employed is given under the particular products covered in this chapter.

Heat and Power. In planning a fish cannery it is particularly important that liberal provision be made for power. Canners require a supply of steam, not only for heating or cooking and cleaning purposes, but also for power. The boiler capacity should be much more than sufficient to take care of the plant when running at full capacity, and it is also desirable to have some reserve in case of breakdown. A boiler that is constantly required to give service up to the limit of or beyond its capacity is in danger of breaking down, and the steam supply is apt to be wet.

Though steam power is used in a few canneries for operating machinery, a far greater number of machines are now operated with individual electric motors.

Cans. The entire end of the sanitary can in use is applied after the filling is done, and the can is closed by crimping or double-seaming the end to the body, no acid or solder being used except on the side seam. A form of cement or rubber gasket is used to assist in making a tight enclosure.

The containers are also classed as plain and enamel-lined, the latter type being used for all fish products. The enamel is a "baked on" type, known as seafood formula "C" enamel, and is universally used for fishery products. A few products,



(*Courtesy L. G. McKee*)

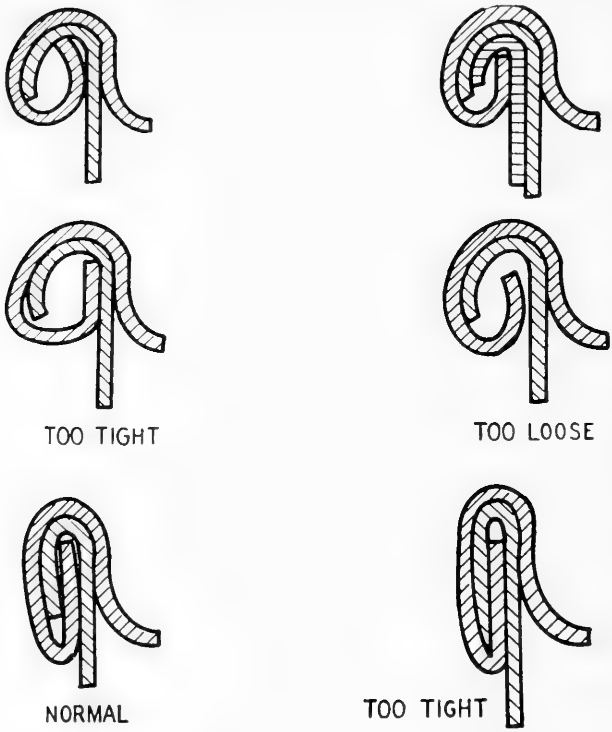
Fig. 20–2. Can sealer rolls (above) and sketch of can (below) showing different parts.

such as shrimp, crab meat, some tuna, and fish flakes, are packed in parchment paper-lined cans, in addition to enamel; this prevents the appearance of any dark spots due to contact of the contents with the metal. Wood and other liners have been used, but parchment paper has now superseded all others. Cans which are exported or those which are likely to be exposed to dampness or salt air are generally lacquered to prevent rusting. A great variety of can sizes are in use so that the consumer may get a product in almost any convenient quantity.

Cleaning and Trimming. In canning fish products cleaning and trimming generally consist of the removal of the head, viscera, and tail fin; the washing of the eviscerated fish to remove blood, etc.; and the trimming of the fish into pieces of proper size to pack into cans. Although in many branches of the industry this work is done by hand, mechanical contrivances have been worked out to a greater or lesser extent in connection with sardine and tuna canning, and have reached a very high degree of perfection in the salmon-canning industry, as will be described later.

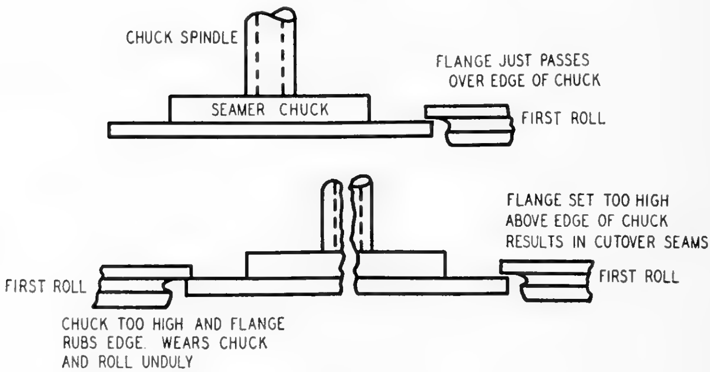
Brining or Pickling. In order to draw the blood from the tissues of the fish and to give the flesh a proper degree of firmness and a desired flavor, many kinds of fish are held in a strong brine for a varied length of time before and after trimming. The time of holding and the strength of the brine used depend largely upon the size and fatness of the fish and the nature of the subsequent canning operations.

Cooking. Many fish, salmon being the most notable exception, are subjected to some cooking or drying process before being packed into cans. This removes



(Courtesy U. S. Fish and Wildlife Service)

FIG. 20–3. Correctly and incorrectly formed can seams. Above, correctly formed first operation seams. Center, seams incorrectly formed by first roll. Bottom, seams formed by second roll.



(Courtesy L. G. McKee)

FIG. 20–4. Adjustments for the can sealing machine. Above, correctly adjusted first operation roll. Below, Incorrectly adjusted first operation roll (misalignment is exaggerated).

excess moisture and supplements the cooking of the fish in the can during the subsequent sterilizing process. In the case of sardines one of two methods is usually followed: the fish are either steamed and dried before packing, or they are dried first and then cooked by a frying process. In some plants a light smoke is given to herring before they are canned as sardines.

Packing. As most fish products, with the exception of salmon, are practically impossible to pack mechanically, nearly all of them are packed by hand. A tuna-packing device is now in the development stage. This machine cuts and forms the tuna into blocks which are the exact size to fit the cans. The entire procedure is automatic, and the exact weight required to fill the can is contained in the one block.

Exhausting. In order to insure a proper vacuum in the cans before sealing and to shorten the time required for the sterilizing process it is common in many fish-canning operations to exhaust the cans before they are sealed; this is done by passing them on an endless belt through a steam chamber for a period varying usually from 5 to 15 minutes and at an approximate temperature of 212° F (100° C).

Sealing. The machines for sealing the cans by rolling the seams have reached such a high degree of perfection that the cans may be sealed at the rate of 200 to 300 per minute.

Sterilization. Is used in this discussion of canning in the broadest sense. Actually canned products are not completely sterilized as meaning that all bacteria are killed. In canning the heat treatment is sufficient to kill only those organisms which would be likely to cause spoilage of the product or be a menace to the health of those consuming it. The time and temperature for the adequate treatment of the various products have been carefully determined. In the references to sterilization below the meaning should be given the broad interpretation and considered as synonymous with processing.

Processing. As canning of food products is based on the principle of sterilizing by heat, the final cooking, or "process" as it is called, is the most vital and important step in the canning procedure.

On account of the solidity with which fish products are ordinarily packed in cans heat penetration is necessarily slow. In order to secure adequate sterilization within a reasonable time it is customary to sterilize such products in retorts under pressure. A temperature varying from 230 to 240° F (110 to 116° C) is ordinarily used.

Testing. After the cans have been cooled, it is customary to test them for leaks or defective seams before they are finally packed in cases for shipment.

Salmon-Canning Industry

Value and Location. On the basis of dollar value the salmon industry is the largest fish-canning operation in America. The largest production of canned salmon is in Alaska, with Washington and Oregon following in the order named. A few salmon are packed in California. Ordinarily, however, the salmon run in this state is not sufficiently large to support the operation of a cannery.

During the 1948 season 4,824,966 cases, valued at $120,537,196, were packed in 123 plants in Alaska, 35 in Washington, 14 in Oregon, and 4 in California. Table 92 (p. 430) contains the statistics of the pack.

TABLE 92. UNITED STATES PACK OF CANNED SALMON, 1948.

The 1948 pack of canned salmon in the Pacific Coast States and Alaska amounted to 4,824,966 standard cases, valued at $120,537,196 to the canners. Compared with 1947 this was a decline of 14 per cent in volume; however, the value of the pack was almost identical with the previous year. Alaska accounted for 83 per cent of the 1948 pack; Puget Sound, 9 per cent; the Columbia River districts of Washington and Oregon, 7 per cent; and the Coast areas of the Pacific Coast States, 1 per cent.

Species	Alaska		Pacific Coast States		Total	
	Cases	Value	Cases	Value	Cases	Value
Chinook or king	53,959	$1,560,674	285,266	$10,197,153	339,225	$11,757,827
Chum or keta	781,888	15,896,244	276,158	5,319,477	1,058,046	21,215,721
Pink	1,304,480	29,541,982	4,480	116,651	1,308,960	29,658,633
Red or sockeye	1,639,902	43,533,904	97,907	4,082,685	1,737,809	47,616,589
Silver or coho	234,313	5,987,786	125,647	3,620,257	359,960	9,608,043
Steelhead	349	8,140	20,617	672,243	20,966	680,383
Total	4,014,891	96,528,730	810,075	24,008,466	4,824,966	120,537,196

Note: "Standard cases" represent the various sized cases converted to the equivalent of 48 1-pound cans, each containing 16 ounces.

TABLE 93. UNITED STATES PACK OF CANNED SALMON 1939 TO 1948.

Year	Alaska		Pacific Coast States		Total	
	Cases	Value	Cases	Value	Cases	Value
1939	5,263,161	$34,441,122	728,943	$7,339,727	5,992,104	$41,780,849
1940	5,069,343	31,474,492	535,663	6,575,176	5,605,006	38,049,668
1941	6,932,040	56,217,601	899,589	11,199,317	7,831,629	67,416,918
1942	5,075,974	48,300,209	759,032	13,673,968	5,835,006	61,974,177
1943	5,428,318	57,824,267	275,889	5,110,847	5,704,207	62,935,114
1944	4,893,059	51,196,140	245,588	5,187,136	5,138,647	56,383,276
1945	4,350,471	44,644,303	557,769	7,942,102	4,908,240	52,586,405
1946	3,949,878	53,157,194	560,289	17,003,459	4,510,167	70,160,653
1947	4,312,286	88,669,542	1,329,226	31,969,134	5,641,512	120,638,676
1948	4,014,891	96,528,730	810,075	24,008,466	4,824,966	120,537,196

Source: U. S. Fish and Wildlife Service.

Catching the Salmon. The salmon industry depends to a great extent upon the spawning migration, for it is only at this time that salmon may be caught in quantity; in fact three of the five species are almost never caught at any other time. Coming in from the open sea in immense schools to spawn, they fall an easy prey to various types of nets, traps, and even hook and line. In general salmon are taken either by "fixed gear" or by "floating gear." The "fixed gear" includes traps, consisting of large stationary pound nets constructed of piling, wire netting, and linen netting. Fish wheels, which are operated by the river current, are still used in some remote sections of Alaska. As they revolve, they pick up the salmon and throw them into a box by the side of the wheels. The "floating gear" includes purse-seine boats, gill-net boats, trolling (hook and line) boats, and floating traps. Sometimes beach seines, dip nets, and spears are also used.

Transportation of the Salmon. The salmon caught in traps are "brailed" out or scooped into scows or cannery tenders. Those caught by hook or by nets are sometimes taken to the cannery in the fishing boats, but more frequently they are transferred to larger boats, known as "tenders," which make regular trips to the places where the fishermen are operating. On arrival at the cannery the fish are either pitched with one-tined forks, called "pews," or sluiced with a stream of water into an elevator which takes them to the cannery floor. The sluicing method is preferable to the use of "pews."

Grading. Salmon are graded as they are unloaded at the cannery. The grades vary among canneries, but in general they are by species, type of gear, and locality of capture. On the Columbia River the grading of "chinook" or spring salmon includes the amount of oil and freshness and the color of the flesh.

Canning Process. The industry is carried on to a large extent in the unsettled and almost inaccessible districts of Alaska. Most of the supplies, machinery, food, labor, and, in short, everything but the fish are brought in by boat. To handle large quantities of fish during the short period when the salmon are running is possible only by eliminating nearly all handwork and using high-speed automatic machinery and conveyors. Indian, Oriental, or other foreign labor are sufficiently skilled for most of the cannery work, but they are never employed as machinists, engineers, cookers, can makers, and in other positions requiring judgment and special training.

The ideal cannery location includes: (1) A plentiful supply of pure, fresh water. (2) Sufficient level ground on which to erect the necessary buildings in healthful surroundings. (3) Sufficient depth of water at the dock to permit the landing of boats at all tides. (4) Nearness to the fishing grounds, which will obviate the necessity of long hauls with the consequent danger of spoilage in transit to the cannery. (5) Provision for adequate removal of waste and sewage.

In general nothing is added in canning salmon except salt; therefore, the strictly manufacturing phases are reduced to a minimum as compared with the canning of other fish, like sardines, tuna, kippered herring, etc. In some canneries oil is extracted from the heads and tail pieces, ordinarily wasted, and added to the canned salmon. This practice is generally only in species, such as the "chum," where the oil content is low. Usually from 4 to 6 ml of the refined head and tail oil are added to each can, the quantity depending upon the size of the can. This enhances appearance and adds to the food value of the canned salmon.

When canning begins the fish are fed by a conveyor or pewed by hand to a table near the fish-dressing and -cleaning machine, known as the "iron chink"—a complicated machine equipped with a series of knives and brushes which rapidly remove the heads, fins, tails, and entrails of the fish under jets of running water. It can handle as many as 3,600 salmon of various sizes per hour. King salmon are usually dressed and cleaned by hand. The next stage is the "sliming" of the salmon; this consists of removing by machine or by hand any remaining blood, slime, loose membranes, etc. After sliming, the dressed fish are fed into a cutting machine, where rapidly revolving knives cut them into slices of the proper size to fill 1-pound or ½-pound cans.

The cans are usually shipped in a collapsed condition from the can factory to the cannery. After the can bodies are made and before the end flanges are rolled on, the cans are collapsed, forming an oval. This is a space-saving practice

as 360 collapsed cans can be placed in a case holding only 48 ordinary cans. The tops and bottoms are packed separately. Before the collapsed cans are used they are run through a machine which expands them and puts on the bottom, thus saving considerable shipping and storing space.

The empty cans are usually stored on the second story of a cannery and fed down a chute into the automatic filling machine, which fills each can with the proper amount of fish and adds the desired amount of salt. A recent type of filling machine cuts the fish into slices, salts the cans, and fills them at the rate of 115

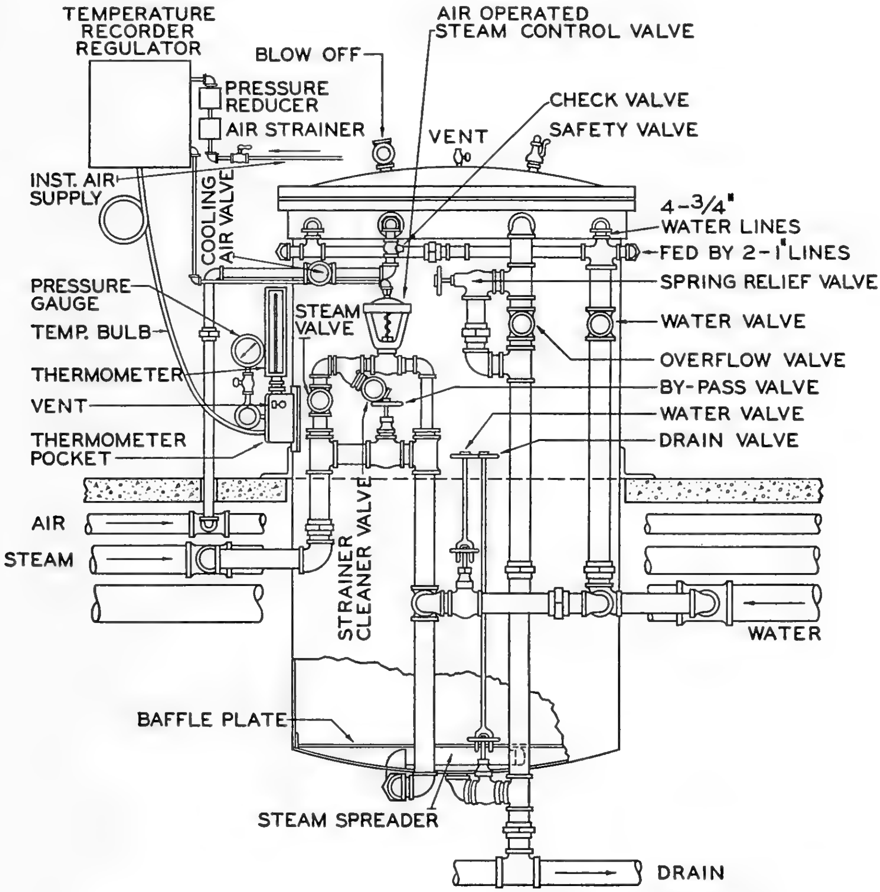
(Courtesy U. S. Fish and Wildlife Service)

FIG. 20–5. The vacuum can sealing machine requires adjustment from time to time. Many canneries make use of this method for sealing cans.

to 125 per minute. Many of the flat cans are filled by hand; this is particularly true when they are to hold chinook and sockeye salmon. The filled cans are then carried on belts to the "patching table," where they are either weighed automatically and inspected to see that they contain the proper amount of fish and have no bones or skin showing at the top. From the "patching table" they pass on moving belts to the "clincher" machine, where tops are loosely crimped on to prevent particles of fish from getting out of and condensation water from getting into the cans during their passage through live steam in the "exhaust box."

The function of the "exhaust box" is primarily to heat the filled cans sufficiently to drive out some of the air; it is necessary to have a vacuum in the cans after

cooling to keep the ends concave under all conditions of temperature and altitude. Usually the cans are exhausted for 6 to 16 minutes with live steam, having a temperature of 200 to 210° F (93 to 99° C). The hot cans from the "exhaust box"



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 20–6. Many of the canning retorts are automatically controlled as to temperature and pressure. This insures efficient operation of the processing.

pass immediately to the "closing machine" or "double seamer," which rolls the tops on firmly, making the cans airtight. In many of the more modern plants the "exhaust box" has been eliminated by use of the vacuum-closing machine. This speeds up the canning operation to a considerable extent. The cans are rolled into "coolers" or large shallow trays, made of flat, iron strips, each holding several dozen cans. Several of these "coolers" are placed on a small car which is rolled on tracks into retorts for "processing" or cooking by steam under pressure.

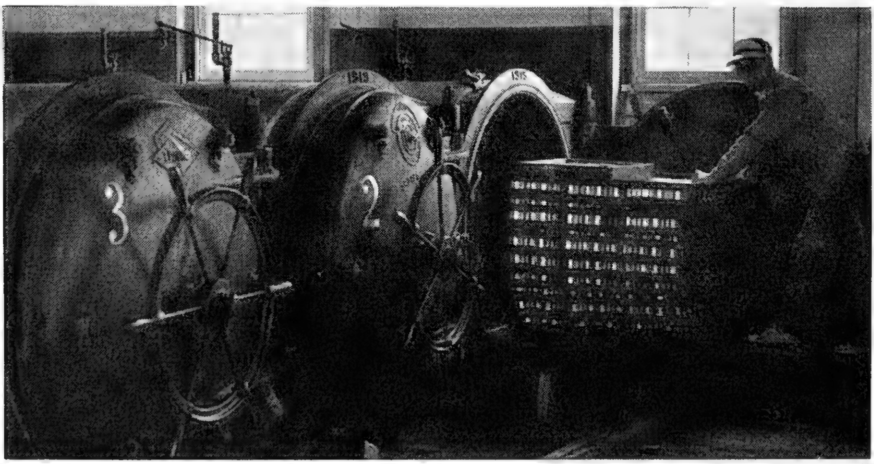
One-pound cans of salmon are usually cooked from 80 to 90 minutes at 240 to 245° F (116 to 118.5° C). The ½-pound cans receive a process of about 70 to 75 minutes at the same temperature. After processing, the cars are rolled out of the

retorts. The coolers, filled with hot cans, are then passed through a "lye wash" to remove oil, washed with clean water, and finally set aside on the floor of a warehouse overnight to cool. As the interior of the cans are at high temperature and pressure, any leaks which are present will show as bubbles of air in the "lye wash." Most of the defective cans are removed in this way; however, they are tested further, after being washed with hot water, by being tapped on the distended ends with a short metal rod. Any can which has a dull sound is discarded, as it is an indication that it is leaking; a ringing sound means that considerable pressure exists within.

Of course, there are some minor variations in methods of canning salmon: such as running the open cans through the "exhaust box," thus dispensing with the "clincher" machine; also, sealing the cans under a vacuum produced by vacuum pumps, thus eliminating the "exhaust box." As already described the cans pass automatically from the filling machine into the "coolers" by means of belts and conveyors; for this reason it is obvious that each piece of machinery, including fillers, "clinchers," "exhaust box," and closing machine, must work in perfect synchronism.

Another type of "exhaust box," which has been installed in some of the canneries, obtains a vacuum in the canned salmon by means of a "steam jet." In this method the filled cans are passed through a short box just before entering the sealing machines. This box is fitted with open steam jets directed at the fish at the open end of the can. After a short exposure to these jets of steam on each side of the line of cans, the lids are dropped in place and the cans are immediately sealed. In using this method it is not necessary to heat the contents of the can to obtain a satisfactory vacuum.

After the retorted cans are cooled, they are sometimes lacquered in an automatic machine. However, there is an increasing tendency to do away with lacquering and to depend on enameled ends and labels to prevent rusting of the cans. The cans



(Courtesy U. S. Fish and Wildlife Service)

Fig. 20–7. After the cans of salmon are sealed they are processed so that they are practically sterile. This is done in a retort under 10 lbs. steam pressure.

are usually labeled by automatic machinery which operates very rapidly. The three common sizes of salmon cans are the 1-pound tall, 1-pound flat, and ½-pound flat. A small amount of salmon is put up on the Columbia River in 1-pound oval and ½-pound oval cans. Salmon are usually marketed in cases containing 48 one-pound, or 48 one-half-pound cans; sometimes 96 one-half-pound cans are put in larger cases.

The scientific and local names for the 5 species of Pacific salmon are given in Chapter 10.

The Canned Product. *Grades.* The principal grading of salmon is by species and locality. On the Columbia River an attempt is made to separate the chinook salmon into three grades on the basis of color and the amount of oil on top of the can, but very little has been done toward grading the other species. Grading by species and locality is unsatisfactory and frequently very unjust. A system based on certain qualities which are uniform for all localities is much needed.

Physical Examination. The quality of canned salmon may be determined from 3 standpoints: (1) the workmanship in packing, (2) the quality of the fish when caught, and (3) the condition of the fish when packed. Of these the last, of course, is the most important.

Well-packed cans should have a good vacuum, from 8 to 12 inches, and should be well filled. The fish should be well cleaned and cooked sufficiently to render the bones soft and easily friable. There should be a definite salty flavor.

The quality of the fish when caught may be determined by the amount of free oil, the color of the flesh, and the presence or absence of characteristic skin markings which develop as the fish deteriorate during the spawning migration.

The condition of the fish when packed is judged by certain physical signs in the canned product. Among these are odor, the appearance of an unnatural reddening of the flesh, "honeycombing," texture, and turbidity of the liquor. Canned salmon of doubtful quality, judged by odor or appearance, may be examined chemically for indol and skatol and for hydrogen or other decomposition products.

Bacteriological Examination. A suitable percentage of the cans should be examined for living organisms. For this purpose they are carefully cleaned, the tops sterilized, and a part of the contents transferred to suitable media. If any microorganisms are found, they are studied further in order to determine the general group to which they belong. In this manner it is often possible to tell whether further spoilage will occur, whether the organisms gained entrance through poorly made seams, or whether they resisted the processing temperature.

Chemical Composition. Clark and Shostrom have analyzed nearly 800 cans of salmon, representing the 5 species of Pacific salmon and the steelhead trout from every important salmon-canning district from northern California to the Yukon River, Alaska. Most of the cans of salmon analyzed were prepared from the second cut of an individual fish. This was done because the composition varies in different parts of the fish, and cans from the same part may be compared better than those from different parts. A summary of the results obtained by Clark and Shostrom is given in Tables 94 and 95 (p. 436).

The food value of salmon depends almost entirely upon protein and fat. The amount of protein in the 5 species does not differ very much, and from a tissue-building standpoint one is about as good as another. The amount of fat differs

TABLE 94. AVERAGE COMPOSITION OF FRESH PACIFIC SALMON AND STEELHEAD TROUT.

Species	No. Individual Fish Analyzed	Moisture %	Ether Extract or Fat %	Protein (N × 6.25) %	Total Ash %	Salt-free Ash %	Calories * per lb.
Chinook (king)	204	63.53	13.50	19.48	2.85	1.18	931
Sockeye (red)	130	64.52	10.84	20.67	2.97	1.29	841
Coho	99	66.26	9.47	20.40	3.15	1.22	778
Pink	90	69.24	6.16	20.56	3.47	1.32	642
Chum	120	68.95	7.42	20.83	2.40	1.24	700
Average all species of salmon	643	66.50	9.48	20.39	2.97	1.25	778
Steelhead trout	32	61.80	14.83	20.46	2.33	1.20	1006

* Calculated by factors of Rubner: 18.6 Cal. for 1 per cent protein, and 42.2 Cal. for 1 per cent fat, on the basis of 1 pound.

TABLE 95. COMPOSITION OF CANNED SALMON.*

Species	Total solids %	Fat %	Protein %	Ash %	Food Value per Pound Calories
Pacific salmon					
Sockeye	35.22	11.22	20.80	1.23	860
Chinook	36.83	15.72	17.67	1.22	991
Coho	32.51	8.49	21.08	1.21	750
Pink	30.20	6.99	21.40	.76	696
Chum	29.96	6.69	20.67	1.02	514
Pacific steelhead trout	33.16	8.95	21.32	1.21	792
Atlantic salmon	35.70	12.49	21.14	1.22	920

* No appreciable difference is found between canned and fresh salmon, as the composition of canned salmon is used here.

greatly, both within each species and between the different species, and so from the standpoint of energy the food value differs greatly. The chinook and sockeye salmon and the steelhead trout possess the most oil and, therefore, the highest food value. When all canning districts are considered, however, many parcels of coho and pink salmon have a higher food value than the average of either of the first 2 species.

Bacteriology of Salmon. The spoilage of fresh salmon has been extensively studied by both the U. S. Bureau of Chemistry and the Seattle Laboratory of the National Canners Association. The decomposition of mature salmon is due to a large number of species of bacteria; while the decomposition of immature and feeding salmon appears to be largely enzymatic, at least in the early stages, followed by general bacterial invasion. The most common organisms isolated by Fellers and Hunter and responsible for salmon spoilage are certain species normally occurring in sea water.

Since many of these bacteria produce indol from certain amino acids formed

from protein, they are often formed in decomposing salmon flesh. Skatol is rarely formed, probably because few bacteria are able to produce it. Only one such organism has been isolated by Fellers, whereas no less than 30 per cent of all cultures examined from decomposed salmon was able to produce indol from salmon flesh.

No pathogenic species of bacteria has been isolated from over 600 cultures from raw and canned salmon. The time and temperature of the process employed in canning salmon precludes the possibility of survival of dangerous bacteria, such as *C. botulinum* or organisms capable of causing gastrointestinal disturbances, unless the cans are accidentally underprocessed. The heat penetration in salmon during the processing has been carefully studied in the Seattle Laboratory of the National Canners Association, and it has been found that the usual process of 90 minutes at 242° F (117° C) is sufficient for preserving the canned product from future spoilage, for eliminating any dangerous organisms that might have been present in the raw product, and for thoroughly cooking the fish and softening the bones.

In the manufacturing process for cans the canning methods and processing times have been brought to such a state of perfection that less than 2 per cent of the pack is found to be defective. The living bacteria which are now found in canned salmon are mainly aerobic spore-formers, such as *B. vulgatus, B. mesentericus, B. cereus, B. subtilis,* and similar species. These are harmless saprophytes and are the common bacteria of dust and soil. The source of these organisms is believed to be the dust in unwashed empty cans since bacteria of this type are not commonly associated with fresh salmon. This theory has been partially confirmed and is now being studied further.

The "exhaust box" in the cannery creates a vacuum in the cans. The vacuum inhibits to some degree the aerobic species of bacteria from developing in well-exhausted cans of salmon. It has also been found that the gaseous oxygen in the can disappears in a few days and is probably held in combination by the contents, thus eliminating the free oxygen remaining after the exhaust. The aerobic, spore-forming bacteria, such as those occasionally found alive in canned salmon, do not produce gas (i.e., swells); although some growth may result, in general no serious spoilage takes place. A few cases have been encountered in the trade where the presence of these species in large numbers materially reduced the grade and market price of the product, though little or no decomposition could be detected by ordinary methods.

Thermophilic bacteria are not common in canned salmon, though a few species have been isolated. A good vacuum in the can effectively prevents further growth of some species of thermophiles. Strict putrefactive anaerobes are also uncommon and are seldom encountered unless the can has a "leak" or has been underprocessed. Furthermore, most species of anaerobes are prolific gas-formers and cause swells. These manifest themselves within a short time after processing, and swells of this nature are usually discarded at the cannery.

Sardine-Canning Industry

All sardines, according to the generally accepted definition, are small fish of the herring family. In California the variety used is the California sardine (*Sardinops caerulea*); in Maine, the sea herring (*Clupea harengus*); in France and

Portugal, the pilchard (*Clupea pilchardus*), and in Norway, the sprat (*Clupea sprattus*).

Canning Methods. The canning methods used for sardines in different localities vary considerably, but consist essentially of washing, salting, cooking, drying, packing, and sterilization.

In France, Spain, and Portugal the fish are dried, fried in oil, and packed; while in Scandinavia a smoking process is commonly used to cook and dry the fish before packing. In the United States the high cost of labor has caused mechanical devices to be more fully developed in packing sardines. A frying process similar to the French method is used for the highest grade of sardines, but most of the Maine sardines and many of the larger sardines packed in California are cooked by live steam and then dried.

Maine Industry. The Maine sardine industry was started in 1875, and since then that state has been the largest producer of sardines in New England. In 1945 sea herring were canned in 15 plants in Maine, while only one plant each was operated in Massachusetts, New Jersey, and Alaska. The industry has spread to the Canadian Provinces of New Brunswick and Nova Scotia. The canning season usually extends from early April until December, and occasionally into January, though this is exceptional. During the latter months of the season larger size fish predominate and are not considered as desirable as the smaller ones. The fish are taken in traps or weirs, which are large circular or heart-shaped enclosures formed by upright stakes and netting into which the fish are diverted by barriers across their course or purse seines used in conjunction with stop nets.

Cannery-owned vessels transport the fish from the place of capture to the plant. Usually only a sufficient quantity for one day's operations is delivered at a time. The vessel pulls alongside the trap or seine and removes the fish by means of a power-operated dip net. The vessels have a capacity of 80,000 to 100,000 pounds of fish at one loading. As the fish are placed in the hold of the vessel, from 200 to 300 pounds of salt are sprinkled over each 1,200 to 1,500 pounds of fish. The salt is a preservative and removes a portion of the water from the fish, causing the flesh to become more firm. Ice is not used for packing as it would bruise the flesh and make it unsuitable for canning.

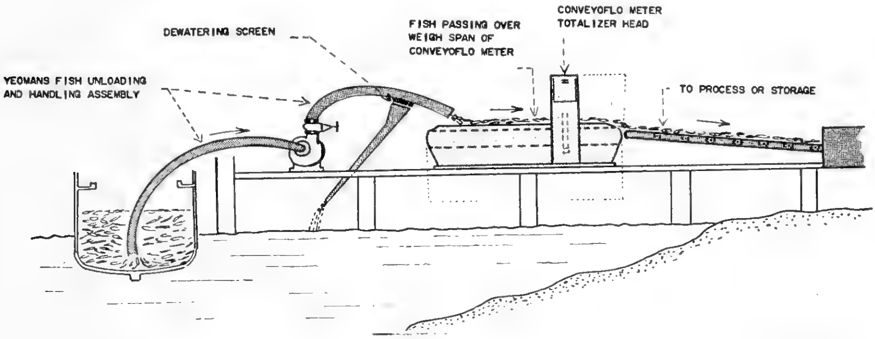
Unloading and Grading. When the transport vessel arrives at the cannery, the fish are inspected for quality and size by state authorities. After inspection they are unloaded by means of buckets which convey them from the hold of the vessel to a flume. A strong stream of water in the flume carries them into the cannery, where they are graded for size. Those between 4 and 10 inches in length, having a maximum amount of fat and a minimum of feed, are preferred.

In some more modern plants the fish are unloaded by means of a large centrifugal pump. The hold of the vessel containing the fish to be unloaded is partially flooded with sea water. The intake of the pump is submerged in the hold and the discharge is placed in the flume. The suction of the pump pulls the fish and water through the pump and discharges them into the flume, by which they are floated into the cannery. It is estimated that 100 tons of fish can be unloaded in approximately 30 minutes by this method.

Flaking. The fish are then spread mechanically on flakes or ¼-inch mesh galvanized wire trays and steamed from 3 to 15 minutes in a steam box or chamber. The racks of steamed fish are next run into large drying chambers, through

which air heated by steam coils is drawn by means of a fan. The drying usually occupies from 1 to 2 hours at a temperature from 100–120° F (38 to 49° C). After cooling, the dried fish are carried on the flakes to the packing tables where women remove the heads and pack them in cans; the larger fish, however, are often dressed on arrival at the cannery.

Oil is then mechanically placed in each can and the cans are passed through the sealing machines which attach the covers. They are then processed or sterilized



(*Courtesy Harry F. R. Dolan, Jr.*)

Fig. 20–8. In many canneries the fish are pumped from the hold of the vessel across a weighing apparatus and into the cannery for processing.

in a few plants by heating for 1½ or 2 hours in boiling water. The cans, while hot, are usually cleaned with sawdust, and after cooling are tested for leaks and packed in cases.

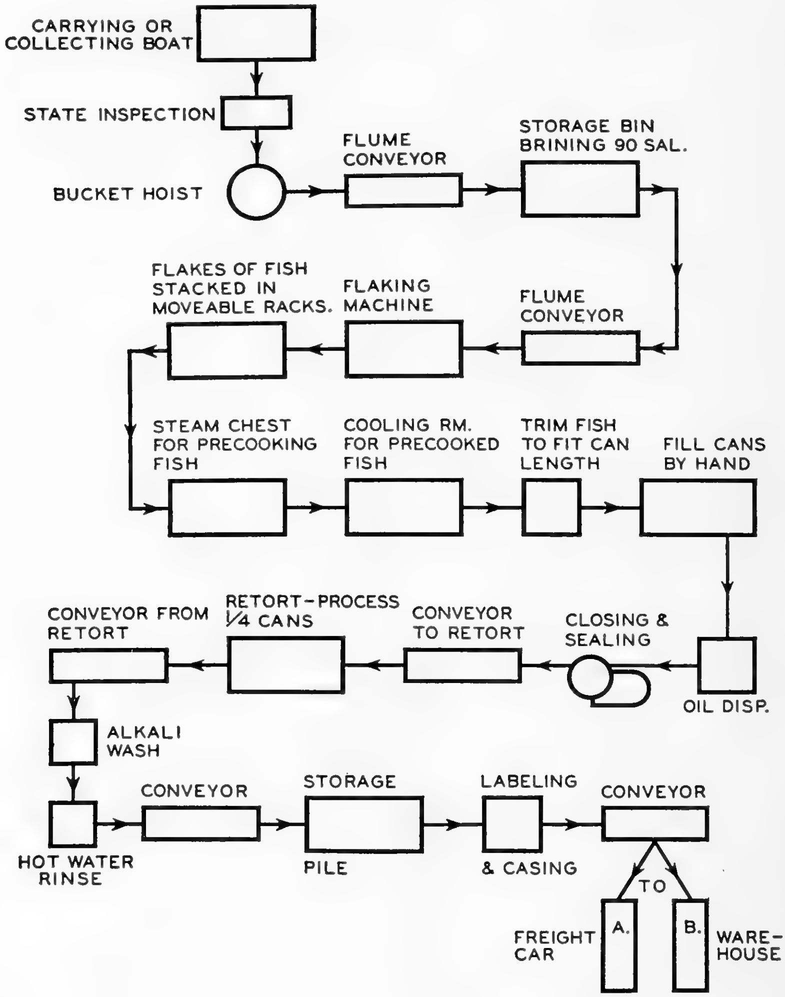
Pressure Sterilization. While some packers still use the hot water method of sterilization, the majority use the more modern pressure method. If the pressure retort method is used, the sealed cans are put in large metal baskets and placed in retorts. When filled the retorts are sealed and dry steam is admitted until a temperature of 240° F (116° C) is attained; this is held for 45 minutes. The processed cans are then removed from the retort and washed to cool and remove the adhering oil.

Improvements in the mechanical preparation of sardines have recently been made through the development of a machine for cutting off the heads of the raw fish. However, a machine of similar type has been in use for many years by a large Maine canner, who also uses a continuous form of drier with belt conveyor. A machine has also been patented for frying the raw fish directly in the cans, but has not yet come into extensive use.

Two types of machines for separating fish according to size are used to some extent, and such separation is essential in connection with the cutting machine. The first consists of a revolving cylinder constructed of coiled pipes set apart at gradually increasing distances, and the second is a number of inclined rotating rollers, the distance between which gradually increases as the fish pass down along them.

A considerable quantity of Maine sardines are fried after partial drying of the raw fish. The frying device most used consists of a long iron tank which contains a

horizontal set of steam-heating coils about 8 inches above the bottom. Water is run into the tank to within an inch or two below the coils, and then vegetable oil, usually cottonseed or olive oil, is added to cover the coils. The oil should be of



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 20–9. Flowsheet for the operation of a Maine sardine cannery.

sufficient depth above the coils to fry the fish in the wire baskets. The temperature of the oil maintained in the fry bath is about 240–260° F (116–127° C).

Smoked Sardines. A few packs of Maine sardines are smoked before packing. The smoking is usually done immediately after the precook. The racks of cooked sardines are placed in the smoke room and the smoke is generated by a low fire covered with birch or beech wood sawdust. The smoking process is known as the "cold smoke" and requires from 3 to 4 hours. An experimental method has been developed by which the smoke is applied after the sardines are packed

in cans; this is done by means of an electrostatic apparatus. After packing, the cans of sardines are conveyed through a tunnel by a metal belt, carrying a positive electric charge which is passed on to the cans. The smoke from the burning wood is directed into the same tunnel and is given a negative electric charge. Through an interchange of electrical charges the smoke is deposited on the sardines. This method eliminates the long smoking time as its action is almost instantaneous.

Sardines in oil constitute the large bulk of the Maine sardine pack, and for this purpose cottonseed oil is most commonly used, 5 to 6 pints being ordinarily required per case of 100 ¼-pound tins. Occasionally sardines, usually of the fancy grades, are packed in olive oil. Of late years olive oil has been difficult to obtain, and few packs have been made with it. Sardines in oil are sometimes flavored with bay leaf, clove, or essential oils. About 1 gallon of oil is absorbed in the frying process for each 5 or 6 cases of sardines fried, depending on the size and fatness of the fish.

Sardines in tomato sauce constitute a large part of the California pack, which is put up in oval tins; while Maine puts up a considerable pack in mustard sauce, containing mustard, salt, pepper, cayenne, turmeric, and other spices mixed with vinegar.

California Sardines. The run of California sardines suitable for canning usually begins in August and continues until February. The seasons for fishing and quantities assigned to canneries and reduction plants are under the control of the State Fish and Game Commission in California. Licenses, specifying allotments of sardines to be used for canning and the percentage for reduction processes, are issued to canneries. These are changed yearly, and it is impossible to state a definite policy governing this fishery. This well-defined seasonal run does not apply to small sardines (less than 7 inches total length), the season and supply of which is very uncertain. Monterey generally has the best season for large sardines; while small sardines are most plentiful off San Diego.

Packing of large sardines in California is generally quite distinct from the small sardine pack. The former are usually put up in tomato sauce in ½- or 1-pound oval cans; while the latter, which require great care and are much more expensive to handle, are packed in oil in ¼-pound cans, and are regarded generally as a luxury.

California sardines are caught in a special net, known as the "lampara," or by a purse seine by the same fishermen who fish for tuna in other seasons. The fish are brought to the canneries on the decks of boats. They are washed and scaled in a revolving cylindrical sieve, and sluiced to the cannery, where they are beheaded and eviscerated by hand. They are then held for about 1 hour in brine of about 70° salinometer scale, the strength of the brine and length of the brining period depending on the size of fish. The fish are then dried and fried by a process similar to that used in preparing fried sardines in Maine, though continuous driers are more commonly used in California.

The fish are allowed to cool thoroughly before they are packed in cans. After sealing, the cans are generally sterilized or processed in closed retorts from 1¾ to 2¼ hours at 220° F (104° C), depending on the size of the fish. The larger sized cans are usually exhausted, that is, heated by passing through a steam box after filling and just before sealing. This insures a good vacuum in the cans and prevents the formation of "springers" later on.

Refrigerated Holding Tanks. The California pilchard industry has developed refrigerated holding tanks for preserving the catch from one day to the next. These tanks containing the fish are fitted with brine circulating systems. The refrigerated brine, containing about 10 per cent salt, is held at 35° F (1.7° C) and circulated through the tanks containing the fish, which are in direct contact with the brine. It has been found that by this method fish can be held in excellent condition for periods as long as 48 hours.

Chemistry and Bacteriology of Sardines. Considerable study has been given to the chemistry and bacteriology of sardines, references to which will be found in the bibliography. Of particular interest is the recent work on changes which sardines undergo in the course of preparation and storage. It has been found that when stored canned sardines show a decided quantity of volatile nitrogenous compounds, the greater part of which is in the form of amines. The percentage of amines appears to correspond directly to the age of the product. During processing or cooking there is an increase in the amount of ammonia and amines. Storage produces a gradual increase of total alkaline material due to formation of alkyl amines and a gradual decrease in ammonia.

The alkaline compound predominating is trimethylamine (which is also extensively formed in the storage of herring in brine and fresh fish in ice). The temperature of storage apparently has a decided influence on the quantity of volatile alkaline compounds formed. This suggests that changes may be due in some instances to bacterial growth; anaerobic, spore-forming, gas-forming bacteria, found associated with the fish, produce both ammonia and amines when grown in fish products. This has a bearing on the detinning of cans and possibly on the softening and maturation of the product.

The principal food of the sea herring, from which Maine sardines are produced, is small animal organisms, including copepods, which constitute the so-called "red feed," and schizopods, small shrimplike animals. With these organisms are associated certain gas-producing bacteria which have a marked deteriorating effect on fish containing feed after they are taken from the water. The problem of avoiding trouble from so-called feedy fish of this kind is one of the most serious connected with the industry.

Herring containing feed in appreciable amounts should be held in the water for a sufficient length of time so that this food may be digested. This can usually be done with herrings taken in weirs; but in the case of fish captured with purse seines and at certain seasons, it is much more difficult. Even fish taken in weirs often contain so much feed that it is impracticable to prepare sardines of good quality, particularly from the small fish; therefore, they are either left in the seines or weirs until the food is digested, or promptly taken to the factory and eviscerated.

Oil for Sardines. Various investigations have been made on commercial olive and cottonseed oils used in the canning of Maine sardines. Sixteen samples of olive oil and 22 of cottonseed oil were included in this study. In testing olive oil for this purpose they found the most valuable information could be secured from the determination of acidity, appearance, and flavor. This does not include tests for adulteration with other foreign oils, for which special chemical or physical tests must be applied.

In the case of cottonseed oil the most helpful tests for quality were the de-

termination of the amount of sediment at 71.5° F (22° C) and the "cloud test." The latter consists essentially of first heating the oil sample to 302° F (150° C) and then cooling it down at once to the point where the cloud appears in the oil. Oils which show sediment at room temperature showed clouding temperatures of not lower than 32° F (0° C), while the best oils gave results of 23.8° F (– 4° C) or lower. As a result of these studies it has been recommended that the following specifications for olive oil and cottonseed oil for packing sardines be observed:

Olive Oil. To be light colored, free from sediment, sweet in taste (not rancid) it shall show less than 1 per cent acidity (calculated as oleic acid) and be guaranteed free from adulteration.

Cottonseed Oil. Summer Oil: It shall be sweet in taste (not rancid) and free from sediment at 70° F (21.1° C). It shall show a "cloud test" not higher than 30° F (– 1.1° C) when tested by the method approved by the American Chemical Society.

Cottonseed Oil. Winter Oil: It shall meet the above requirements, except that it shall be capable of withstanding a "cloud test" of 21° F (– 6.1° C).

The composition of various types of Maine sardines is given in Table 96.

TABLE 96. PROXIMATE COMPOSITION OF SARDINES AS CANNED.

Fish	Moisture	Total solids	Total nitrogen	Protein (N × 6.25)	Ether extract	Ash	Calcium	Phosphorus	Iron	Calories per
			g. per 100 g.				mg. per 100 g.			100 g.
Pilchard, Cal. "natural" pack	65.2	34.8	2.83	17.7	13.5	2.9				192
Pilchard, Cal. tomato pack	65.1	34.9	2.86	17.9	13.8	2.7				196
Sardines, in mustard	68.6	31.4	3.15	19.7	7.9	3.7	279	403	5.2	150
Sardines, in oil (drained)	61.6	38.4	3.76	23.5	12.7	3.1	363	488	1.4	208

Norwegian Sardine Canning. The canning center of Norway is Stavanger, which is the principal shipping point for Norwegian canned fish. There are about 80 brisling and herring canneries in Norway. The canning season lasts from about June 1 to December 1, while fish balls and other products are put up during the rest of the year.

Following is a description of the canning process, according to Hamm (1947):

"The fish used for the canning of Norwegian sardines is that known in Norwegian as 'brisling' and in English as 'sprat' (genus, *Clupea sprattus*). A lower grade of sardine is put up from the small herring or 'mussa' (*Clupea harengus*) or from a mixture of these with brisling. These fish are from 3½ to 5 inches in length.

"The summer fishing season lasts from about June 1 until October 15. During this season the brisling or mussa are caught in the fjords where they are driven by the whales. They are caught by large purse seines, which are carried out around the fish by small boats. As this is the spawning season, the fish are left in the nets from 3 days to 1 month before being taken out of the water so that their condition may be perfect for canning.

"The first thing done with the fish in the canning factory is to put them through a thorough washing process in large tubs. They are then placed in other tubs in brine.

After remaining in the brine from 20 minutes to a half hour, they are taken to another department and placed on tables. Here they are placed in long rows of little grooves in which a wire rod is run through the eye of each fish. Each rod, with 22 fish on it, is then hung on a flat frame, 30 rods on each frame, making 660 fish on a frame. Ten of these frames are then placed one above the other, with the 6,600 fish hanging from them, in a crate or larger frame. This is wheeled into one of the many smoking ovens, where the fish are smoked for 30 minutes or so, the length of time depending upon the condition of the fish. They should be lightly smoked and cooked, but not enough to brown them, as the fine silvery finish must be retained for canning.

"The fish are then taken from the smoking ovens to the cutting machine, where their heads are removed. The fish are then sorted by hand ready for packing in uniform sizes in the cans. Girls then pack the fish in the cans by hand.

"Before the lid is put on the can, it is put through a machine that places a small rubber band inside the lid. The lid-fastening machines then clasp and hermetically seal the lid on the can. No solder is used in covering and fastening the lids nor in making either lids or cans. The cans are then sterilized by intense heat, varying according to the size of the can. Later the cans are labeled, the key inserted, and the tins wrapped in paper and packed 100 to the case. For all fish not packed in oil, tins lacquered on the inside are used. This is to prevent corrosion of the tin. Oil itself prevents corrosion."

Formerly a considerable quantity of Norwegian sardines were packed with olive oil. This is now so expensive that it has been replaced by herring (sild) oil. The sardine oil used is deodorized and winterized and added to the cans by machine after the fish are packed in the can. The Norwegian industry packs both herring (sild) and brisling as sardines.

French Sardine Industry. The French sardine is prepared from the pilchard (*Clupea pilchardus*), which is caught extensively off the west coast of France, Portugal, and Spain. The fish are taken in nets, being attracted to the fishing grounds by the use of cod roe as bait. The season for pilchards is from May to September. Fishing is generally a separate business from the canning, the canners buying their supply of fish from fishermen.

On arrival at the canneries the fish are sprinkled lightly with salt, and the head and viscera are removed by hand. They are immediately transferred to strong brine for ½ to 1 hour, after which they are put into wicker baskets and washed. The drying operation is the next step, the fish being arranged vertically tails up in special wire-meshed trays and dried in the open air; in damp or rainy weather artificial heat is generally used. When sufficiently dried the fish are fried in the same trays by immersing them in tanks of hot oil. Peanut oil is often used for frying as well as olive oil. The time for frying depends on the size and dryness of the fish, but is usually about 2 minutes. The surplus oil is allowed to drain off on a sloping table; after cooling, the fish are packed usually in olive or peanut oil, in cans. The covers (in this case the bottoms) of the cans are soldered on by hand, the can being revolved on a small, foot-operated turntable. The cans are processed by immersion in boiling water for 2 hours.

Various essential oils and other ingredients, such as oil of lemon, cloves, bay, truffles, and pickles, are used to give added flavor to French sardines. They are put up in cans of a large variety of sizes and shapes. The standard type is the "quarter" can which usually holds from 8 to 14 fish. The "half" can is twice as large and the "eighth" one-half as large. Oval and oblong cans of special design are also common. The quality of sardines depends largely on proper salting and

cooking, though the character of the oil used is also very important. The fish should be uniform and of medium size to make the best product.

Tuna-Canning Industry

According to tradition Mr. A. P. Halfhill deserves the credit for starting the tuna-canning industry. He had been canning sardines for about 10 years when in 1903 the sardines failed to appear. This circumstance threatened to close the canneries for the season. However, Mr. Halfhill was familiar with the tuna, which was abundant off the Coast of California, as well as the Italian pack of "Tunny." After some experimentation he was successful in preparing a satisfactory pack. In 1903 700 cases were packed in San Pedro; these were sold on the market for $5.00 per case. In 1948 6,340,172 cases were packed, and the wholesale price was $22 per case for fancy white meat tuna and $17.25 per case for light meat tuna.

Species of Tuna. *Yellowfin* (*Neothunnus macropterus*): This species averages about 30 pounds in weight although individuals may be as small as 7½ pounds and as large as 300 pounds. The size-limits for landing are controlled by state laws.

TABLE 97. PACK OF CANNED TUNA AND TUNALIKE FISHES, 1948.
Standard Cases

Species	California		Washington and Oregon		Maine, Maryland, and Massachusetts		Total	
	Cases	Value	Cases	Value	Cases	Value	Cases	Value
Albacore	879,814	$16,366,937	419,429	$8,192,381			1,299,243	$24,559,318
Yellowfin	3,891,612	60,262,399	126,341	2,090,436			4,017,953	62,352,835
Bluefin	[1] 148,778	2,378,079					[1] 148,778	2,378,079
Skipjack	1,026,706	15,905,662	23,732	389,842			1,050,438	16,295,504
Bonito	185,363	2,392,346					185,363	2,392,346
Yellowtail	188,776	2,238,982					188,776	2,238,982
Mixed species	27,780	437,075	3,388	53,361	26,729	$360,288	57,897	850,724
Tonno, solid	89,167	1,542,508					89,167	1,542,508
Total, solid	3,919,132	64,881,667	388,099	8,032,772	[2] 26,729	[2] 360,288	4,333,960	73,274,727
Total, flakes	2,518,864	36,642,321	184,791	2,693,248			2,703,655	39,335,569
Grand total	6,437,996	101,523,988	572,890	10,726,020	26,729	360,288	7,037,615	112,610,296

[1] Includes a few cases of Atlantic Coast little tuna, packed in California.
[2] Includes flakes.

Note: "Standard cases" represent the various-sized cases converted to the equivalent of 48 No. ½ tuna cans to the case, each containing 7 ounces net weight of solid meat or 6 ounces net weight of flakes or grated. Total pack in Washington amounted to 90,253 cases, valued at $1,643,697, while the production in Oregon totaled 482,637 cases valued at $9,082,323. The actual cases packed were as follows: 6,891,649 cases were packed in the No. ½ tuna (48 cans to the case); 72,717 cases were packed in the No. 1 tuna (48 cans to the case), each can containing 13 ounces net weight of solid meat or 12 ounces net weight of flakes or grated meat; and 614 cases of miscellaneous sized cases. Tuna and tunalike fishes were canned in 30 plants in California, 14 in Washington, 13 in Oregon, 3 in Massachusetts, and 2 each in Maine and Maryland.

Bluefin (*Thunnus thynnus*): This species is second in importance from the standpoint of the volume of the pack. The average weight is 30 pounds, though individuals are often both larger and smaller than this size.

Skipjack (*Katsuwonus pelannis*): This is the smallest of the tunas, and is also known as the striped tuna from the markings on the body. It averages about 10 to 12 pounds in weight.

Albacore (*Germo alalunga*): This is the first species canned in California and the only one which can be labeled as white meat tuna. The pack of this species was greater than all the others combined until 1925, when, for some unknown reason, the catch declined and has never come back.

Bonito (*Sarda chiliensis*): This species has a flesh that is somewhat darker in color and stronger in flavor than the others. It ranges, in considerable number, as far north as Alaska.

Yellowtail (*Seriola dorsalis*): This species is canned to some extent in Mexico, but the canning of those caught in Californian waters is prohibited. It ranges south from California to the Galapagos Islands.

Fishing Methods. The tuna fishery has become a year-round fishery; with large refrigerated "clippers" it is possible to range several thousand miles in search of fish. During July, August, and September fishing is usually done near the coast of California, and during the remainder of the year the vessels range farther. The smaller vessels which do not make long cruises use crushed ice as a refrigerant.

The tuna vessel is an especially constructed type, 65 to 145 feet in length, fitted with radar, loran, radio direction finder, automatic pilot, depth-sounding devices, and radio telephone. The capacity of the vessels ranges from 40 to 450 tons of tuna, with a cruising range of several thousand miles. They are equipped to fish with hook and line and purse seines. The purse seines are responsible for a considerably greater portion of the catch than the hook and line.

When the vessel using the hook and line method sights a school of tuna, live bait, small pilchard, or anchovies are thrown overboard from the bait tank. Fishermen stand on a specially designed rack and fish with lines and barbless hooks. When the tuna strike the hook, they are thrown on board by the heavy pole and are released by the barbless hook as soon as they land on deck. The hooks are made in the form of a lure, called "squid" or "jigs." If the fish are particularly large, 2 or 3 men work as a team on one hook.

Purse-seine fishing does not require the use of bait since the school of tuna is surrounded by the seine and held near the vessel. The fish are dipped from the seine with a power-operated dip net. They are loaded through deck plates into chilled brine in tanks in the hold of the vessel. When the fish have been chilled to the temperature of the brine, the brine is pumped overboard. The fish are then completely frozen by the refrigeration coils in the tanks. They are held frozen until landed at the canning plant. The purse-seine method of fishing has resulted in an increase in the production of tuna since it is possible to fish even when small pilchard or anchovy bait are unobtainable.

Delivery at the Canning Plant. On arrival at the cannery wharf the fish are unloaded by hoisting them from the hold of the vessel in large metal buckets or boxes. These are dumped into flumes which carry the fish to the scale house where their weights are taken and recorded. The crews of the vessel are paid according to the weight of the catch. After being weighed the fish are conveyed into the cannery by flume.

The tuna must be defrosted before they are canned. Crystals of ice formed in the flesh of the fish when it is frozen cause damage unless defrosting takes place slowly. Several methods are in use for defrosting. The water of the flume removes some of the frost. In some plants the tuna are placed on the floor at

atmospheric temperature, and in still others tanks of water receive the fish to be defrosted.

Butchering and Inspecting. When the tuna are completely defrosted, the heads and viscera are removed. The body cavity is washed thoroughly to remove all traces of blood. A State Health Department inspector examines them for decomposition before the process is continued. This examination insures that only those in first-class condition reach the cans.

Precooking. The tuna are placed on racks which are run into large steam chambers or cookers. The cooking time is usually from 2½ to 4 hours at 212 to 216° F (100 to 102° C), depending on the size and condition of the fish. The racks are then run out and allowed to cool in an air current for at least 12 hours,

(Courtesy U. S. Fish and Wildlife Service)

FIG. 20–10. The eviscerated and cleaned tuna are placed in racks or baskets for precooking. This removes the excess oil and softens the flesh so that the skin and bones can be removed.

or until the flesh has become firm enough to be handled without being broken. The fish are then easily skinned and beheaded, and separated into 4 longitudinal sections. After removal of the dark meat the strips of white meat are cut into proper lengths to fit the cans, into which they are packed, and salt and oil are added mechanically. Cottonseed oil is commonly used, ¾ of an ounce for each No. ½ (7-ounce) can. The dark meat is also canned to a considerable extent, but

does not command as high a price as white meat. A machine for molding blocks of tuna meat the exact size for the can is in operation in some canneries.

In order to heat the cans and get a better vacuum after sealing they are first passed through an "exhaust box," an enclosed steam chamber through which a conveyor runs, and then sealed.

Closed horizontal retorts are generally used for "processing" or sterilizing the canned tuna, the usual process temperature being 240° F (116° C). The time averages 50 minutes for No. ¼ cans, 55 minutes for No. ½ cans, and 70 minutes for No. 1 cans.

To prevent the cans from being damaged by too sudden a release of external pressure when the retorts are opened, the cans are usually cooled under pressure by introducing compressed air and water into the retorts before opening.

Methods of canning yellowtail and bonito are very similar to those followed for tuna.

Recently there has been considerable demand for California tuna packed Italian style. Bluefin tuna (or striped tuna) is used for this product, which is more heavily salted than the regular canned tuna and is packed in olive oil.

Grades of Tuna. About 80 per cent of the pack of tuna is placed in ½-size (7-ounce) flat cans. Other size containers used are ¼ and 1 pound. The following 4 grades are ordinarily packed:

Solid pack—Fancy, contains only the choicest cuts of meat.

Standard pack—75 per cent of the pieces is small.

Flake—Consists of small pieces left over from the other packs.

Shredded or grated—Light meat treated so that the pieces are of uniformly small size.

Other Fish-Canning Industries

Mackerel. In Maine the mackerel, after delivery to the cannery, are dressed by splitting, by removing heads, tails, fins, and viscera, and by washing. The fish are next held in strong brine until the desired saltiness is secured, and are then packed and sealed in oval cans, usually with a little vinegar and spices added. The sealed cans are cooked and sterilized in boiling water.

In 1948 57,653,640 pounds of mackerel valued at $9,850,843 were packed on the Atlantic Coast; this includes Jack mackerel. There were 68 canneries in operation making this pack. The cases of this product contain 45 pounds, which indicates that 1,281,192 cases were packed.

A few packers prepare "fillets of salt mackerel." In the preparation of this pack the mackerel are first brined and then filleted. The fillets are packed with brine and a small amount of vinegar in 1-pound, oval "C" enamel cans. The cans are sealed and processed after the usual method. The can size used is that known as the 1-pound oval and contains 12 ounces of fish.

The canning of the chub mackerel (*S. japonicus*) on the coast of California has developed to considerable importance, having first been canned experimentally by the tuna canners of southern California.

The method of canning consists of the following steps: The fish are scaled and eviscerated, the head and fins being removed by a specially developed mechanical apparatus. The dressed fish are put into 75° Sal. brine until blood is extracted, and then rinsed in fresh water and packed tightly in No. 1 tall cans. The full

cans are inverted on wire mesh racks and cooked in retorts with live steam for 45 minutes at 3-pounds pressure. After draining for about 30 minutes the cans are reversed, the backbones of the fish removed, the cans repacked, and about ½-ounce cottonseed or other vegetable oil added. The cans are exhausted for about 10 minutes at 212° F (100° C), and then sealed and processed 1½ hours at 240° F (116° C), or 2 hours at 230° F (110° C).

Herring. Large herring are canned plain or kippered to some extent in Maine, on the Pacific Coast, and in Great Britain, the methods used being similar in the three localities. Other canned herring products are put up in European countries bordering the North Sea.

In Maine herring running 10 inches or more in length are used for plain canned herring. The fish are beheaded, dressed, and held in strong pickle (from 70 to 80° Sal.) for about 1 hour. They are then packed vertically in tall 1-pound cans and steamed in retorts 30 minutes at 230° F (110° C). After being sealed hot they are processed 2 hours at 240° F (116° C).

Kippered Herring. The fish are dressed and pickled in brine as for plain herring. They are next strung through the tails on wooden rods of about ½ × ½ × 24 inches, through which long nails are driven a few inches apart. The rods are placed close together in horizontal rows on frames built in a smokehouse, and these rows extend one above the other to the top of the building and to within about 6 feet of the floor. The fish are exposed for 18 to 24 hours to the smoke and heat from a smoldering fire of birch or other hard wood which dries them and gives them the slightly smoky flavor desired. The fish are then removed and packed by hand in 1-pound oval cans. The cans are sealed without further addition and are processed in a bath of boiling water for about 2½ hours.

Marinated Fish. Bismarck herring are prepared by washing choice herring of uniform size in a revolving cylindrical screen, which also removes the scales. The fish are then dressed by removing heads, tails, and bones by hand, and rinsed and placed in about 75° brine for 2 or 3 hours. From the brine tanks they are transferred to a vinegar pickle of 5 to 6 per cent acidity, containing considerable salt. After about 2 days the fish are ready to pack in cans, in which they are placed in layers, with onions, peppers, and mustard seed on each layer. A small amount of 2¼ per cent vinegar and a little sugar are added to each can, which is exhausted, sealed, and processed.

Rollmops. These are prepared by spreading the boned and pickled herring on a table and rolling each piece around a salted cucumber pickle or onion. The rolls are fastened with wooden pins, packed in cans, and after peppers, allspice, mustard seed, bay leaf, paprika, a slice of pickle, and a little vinegar are added, the can is exhausted, sealed, and sterilized.

The preparation of marinated fish, rollmops, and other miscellaneous products is described in greater detail in Chapter 21.

Shad. Shad is so highly esteemed in the fresh state and the supply on the Atlantic Coast has been so limited in recent years that it is not canned there. This fine food fish was introduced on the Pacific Coast about 50 years ago and has become well established in the Sacramento and Columbia rivers, where it is caught to a limited extent by the salmon fishermen when salmon are not plentiful, and is canned by a few of the salmon canners.

The fish are scaled, split, and dressed. After thorough cleaning they are cut

transversely in pieces to fit the 1-pound tall salmon can in which they are usually packed. Cans are exhausted about 4 minutes and processed at 240° F (116° C) for 80 minutes.

Fish Flakes. A canned product of considerable importance has been developed in recent years on the New England Coast through the use of cod and haddock for the canning of fish flakes. Fish prepared in this way resemble fresh fish much more closely than do foods prepared from the dry-salted fish.

The fish are dressed, cleaned, and then held in large tanks under brine to extract the blood and acquire the desired flavor. The time in brine depends upon the form and size of the fish. After they are removed from the brine, they are skinned and the napes carrying the fine bones are removed.

The fish are then placed on trays and run into retorts where they are cooked by live steam until tender. They are then removed from the retorts and carried while cooling to the packing room where the backbones are removed. The tender meat of the fish is broken up into flakes and packed into cans. The cans are exhausted for about 10 minutes at 212° F (100° C) and after sealing are processed at 240° F (116° C). Two sizes of cans are used, one containing 7½ ounces of fish and the other 11½ ounces. The cans are lined with parchment paper to prevent discoloration.

Fish Roe. The canning of fish roe has formed a considerable industry in Russia, where the roe of two species of sturgeon are converted into the highly prized black caviar of commerce. Of late years this industry has greatly declined, both on account of the scarcity of the raw product and the unsettled conditions in that country. Imitation caviar is put up in considerable quantities in Germany and the United States from the roe of other fish.

River herring roe is canned to a limited extent on Chesapeake Bay, and shad roe on the Columbia River. Herring roe intended for canning are collected in buckets as the fish are cut and washed in fresh water in special trays, blood and adhering particles of entrails being removed. As the roe swells considerably in processing, the cans must not be tightly packed. They are filled with roe to within about ¾ of an inch from the top, the remaining space being reserved for cold salt brine. The brine is added solely for seasoning, and consists proportionately of 1 pound of salt to 8 or 10 gallons of water. The cans are immediately capped and placed in the processing baskets. In some canneries the filled cans are placed in the "exhaust box" for about 10 minutes. Upon removal from the exhaust necessary air space is provided by pressing the roe down with a plunger. Material clinging to the flange where the top is to be crimped is removed with a brush. Canned roe are processed in a closed kettle for 45 to 55 minutes at a temperature of 240 to 245° F (116–118.5° C) (for No. 2 cans). Milt roe may be canned in the same manner, except that the cans can be more completely filled as this product does not swell in processing. Since the quantity of brine used in this case will be somewhat less, it should be made correspondingly stronger.

Codfish Cakes. Codfish cakes are canned to some extent in the New England area. This is composed of approximately ⅓ shredded dry-salt cod fish and ⅔ potatoes, with a small amount of citric acid, pepper, and salad oil added. The potatoes are peeled, boiled, and mashed, after which the shredded cod fish is added, the whole thoroughly mixed, placed in cans, and processed. It is packed in various size cans and is ready to fry in deep fat in the form of "cakes" or balls.

Pet Food. A considerable quantity of waste material from the fillet-cutting industry is prepared as pet food. This material consists of the backbone with adhering flesh, trimmings from the fillets, and in some instances the heads of the fish.

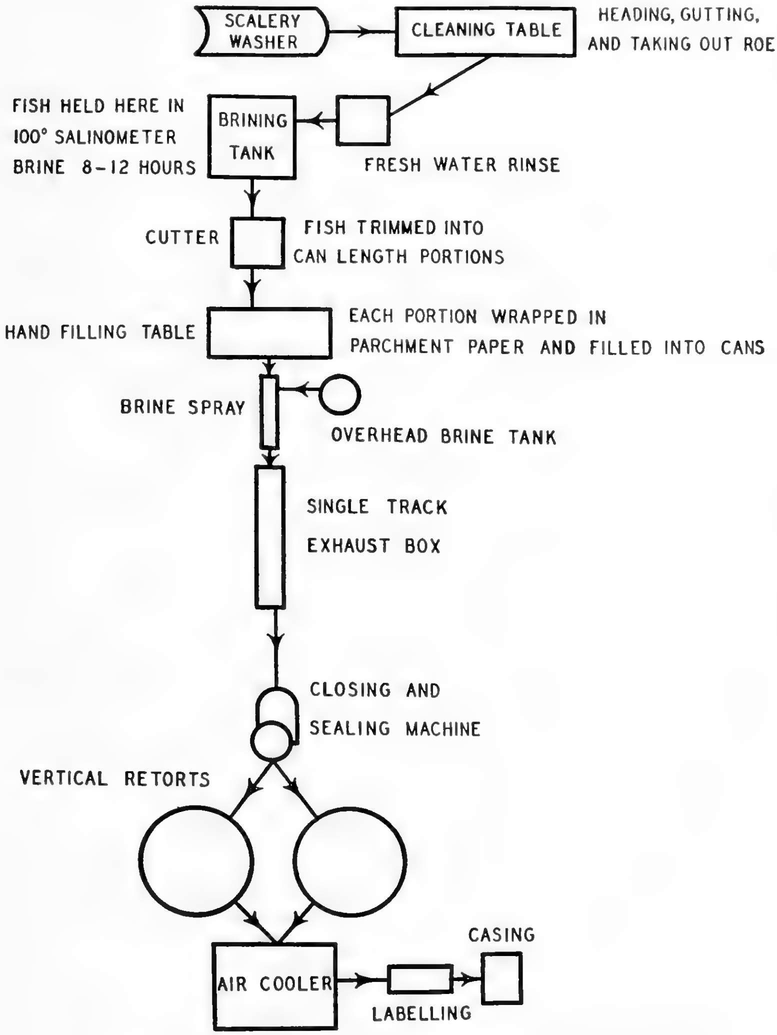


FIG. 20–11. Flow sheet for the canning of river herring.

It is boiled in large kettles, passed through a meat grinder, and mixed with several other ingredients in order that it may be a well-balanced food. These ingredients consist of fish, 30 to 35 per cent; cereal, 30 to 35 per cent; vegetable, 10 per cent; dried milk, 2½ to 3 per cent; cod-liver oil; and yeast. The whole is thoroughly mixed, placed in No. 1 cans, and processed. Each packer has developed his own particular recipe, which is usually considered secret. The bones are softened during processing, and furnish calcium and phosphorus.

TABLE 98. CANNING OF FISHERY PRODUCTS—CONDENSED PROCEDURES AND PACKING DATA.

Product	Season	Cleaning loss	Pretreatment	Blanch or precook	Total loss	Exhaust	Closing temperature
		%			%		° F
Salmon:							
Chinook	Varies from year to year according to necessity for conservation of supply. See fishery regulations for Alaska, British Columbia, Washington and Oregon. In general, June through September.	30	Wash and cut in container length pieces.	None	30	Vac. seal	Room temp. (60–70)
Red		33	do	do	33	do	do
Coho		33	do	do	33	do	do
Pink		35	do	do	35	do	do
Chum		33	do	do	33	do	do
Sardines:							
California	Northern dist. Aug. 1 to Feb. 15. Southern dist. Nov. 1 to Mar. 30	No data	Brine 45 to 90 min.	1. Raw pack.	50	Vac. seal	70
				2. Fry—large, 7 min.; small, 4 to 6 min.		12 to 15 min. ex.	150
				3. Steam exhaust, 25 to 40 min.		Sealed hot	150
				4. Steam exhaust, 20 to 25 min., then through superheated steam, 240 to 260° F		do	150
				5. Oven cook, steam and gas 20 to 40 min.		do	150
				6. Oven cook, gas, 45 min. "Ullman" Cooker.		do	150
Maine	Apr. 1 to Dec. 1, most of canning during period July 1 to Aug. 1.	15 (small fish)	Salted in boat, 280 lb. to hogshead (1200 lb.)	Steam 18 to 20 min., 212–220° F	35 to 41 (small fish), 55 to 60 (large fish).	Cold fill, no exhaust	65
Mackerel:							
Boston	July 15 to Oct. 1	30	Brined 1 hour in 100° brine. (salt mackerel—12 hours in 100° brine).	Raw	50	15 min. at 210° F	160
California	July 1 to Oct. 1	30	Brine 1 hour in 80 to 90° brine.	Raw	60	20 to 45 min. at 210° F	180

Tuna:*								
Albacore	July 1 to Aug. 1 (Calif.)	No data	Clean and wash	10 to 14 lb. 3–3½ hrs.	216–220° F	60 to 64	3 min. 210° F	70
	Aug. 1 to Oct. 1 (Oregon)			18 to 40 lb. 4–4½ hrs.	do		(Some packs vac. seal.)	
Bluefin	June 15 to Nov. 30	do	do	8 to 18 lb. 2 hrs.	do	60 to 64		
				18 to 50 lb. 3 hrs.	do			
				50 to 60 lb. 4 hrs.	do			
				60 to 200 lb. 5 hrs.	do			
Yellowfin	Jan. to Dec. 31 (generally more abundant in summer months).	do	do	8 to 18 lb. 2 hrs.	do	60 to 64		
				18 to 50 lb. 3 hrs.	do			
				50 to 60 lb. 4 hrs.	do			
				60 to 200 lb. 5–9 hrs.	do			
Striped	Aug. 15 to Nov. 30	do	do	5 to 12 lb. 2–2½ hrs.	do	60 to 64		
Alewife or river herring.	Apr. 1 to May 15	30	Brined 8 to 12 hours 100° brine.	None		30 to 35	3 min. 210° F also filled with hot brine or water.	100 (approx.)
Fish flakes (haddock)	Apr. 15 to May 15 or at other times depending on fresh fish market.	40	Brined 10 to 14 hours 100° brine.	Steam 30 min., 240° F		70	Hot fill	150
Finnan haddie	Nov. 1 to Feb. 15	40	Brined 20 to 40 hours 100° brine, then smoked 10 to 14 hours.	Fillets steam 15 min., 240° F (whole fish 30 min.)		70	Hot fill	150
Shad	Calif. Apr. 1 to May 15 Columbia River May 1 to July 1	25	Wash, cut in container length pieces.	Raw fill		35	Vacuum seal	60
Clams:								
Razor	Apr. 1 to May 31	65	Wash	Steam		65	Vacuum seal and hot fill.	150
Soft	Oct. 15 to Jan. 1 and Mar. 15 to Apr. 15.	65	Wash	Steam 20 min. 212° F, 15 min. 228° F		75	Hot fill	150
Oysters:								
Atlantic or Gulf	Jan. 1 to May 1	75	Wash	Steam 5 to 8 min. 245° F		93	Hot fill	150
Pacific	Nov. 15 to May 1		Wash	Steam 3.5 to 4 min. 240° F		80	Hot fill	160
Crab, Dungeness	Apr. 1 to Nov. 1 (Alaska—closed season during this time) Jan. 1 to Jan. 1 (Ore. Wash.)	73	Shelled alive, washed	Boiled 20 min.		75	Vacuum seal	80
King (Japanese)	May 1 to Aug. 1	No data	Shelled alive, washed	Boiled 15 to 20 min. 25° brine		No data	Heat exhaust 7 to 10 min. 210° F	165

* The season given applies only to California. Tuna of the various species are found on some part of fishing grounds throughout the year.

TABLE 98. CANNING OF FISHERY PRODUCTS—CONDENSED PROCEDURES AND PACKING DATA. (*Continued*)

Product	Season	Cleaning loss	Pretreatment	Blanch or precook	Total loss	Exhaust	Closing temperature
		%			%		° *F*
Shrimp	Apr. 15 to June 30 and Aug. 15 to Mar. 15.	55	Brine soak 30 min. 50°	Wet pack 5 to 7 min. Dry pack 7 to 12 min.	75	Hot fill Vacuum seal	150 85
Clam chowder	Oct. 15 to Jan. 1 and Mar. 15 to Apr. 15.	75	Solid ingredients diced	Potato 2 to 3 min.	75	Hot fill	180
Fish chowder	Apr. 15 to May 15	40 fish, 20 potato	Fish brined 10 to 12 hours 100° brine, potato peeled, washed, diced.	Potato 2 to 3 min., fish, steam 30 min. at 240° F	70	Hot fill	160
Fish cakes	Aug. 15 to Jan. 15	20 potato	Wash and peel potato. Soak salt cod 10 hours.	200 lb. potato, 100 lb. cod. Boil 30 min. (212° F)	20	Hot fill	150
Fish roe:							
Alewife (river herring)	Apr. 1 to May 15	5	Rinse	Raw fill	5	Heat exhaust 3 min. 209° F and hot fill brine.	80
"Deep sea" (Cod and haddock)	Dec. 15 to Apr. 15	None	Ground and mixed with brine.	None	None	15 min. 210° F	180
Shad	California Apr. 1 to May 15. Columbia River May 1 to July 1.	10	Wash, skin and slime.	Raw fill	10	8 min. 210° F Some use no exhaust.	150 60

Product	Brine or sauce	Fill * Weight	Fill * Can size	Process Time	Process Temperature	Yield	Remarks
		Ounces		*Minutes*	° *F*		
Salmon:							
Chinook	¼ oz. salt added to each can. No brine.	16.6	No. 1 tall	90	240 to 245	1 to 5 fish per case	Col. River chinook only part of pack graded for quality and is mostly hand packed.
		16.2	No. 1 flat	do	do		
		8.0	No. ½ flat	80	do		
Red	do	3.9	No. ¼ flat	70	do	12 to 13 fish per case	This species in demand because of deep red color and excellent flavor. Use of lighter colored species has given rise to rumors that some fish are dyed and sold as salmon, which is entirely false. It is not permitted by law and technical difficulties of such ap rocess are practically insurmountable.
		16.0	No. 1 oval	90	do		
		7.9	No. ½ oval	80	do		
		3.9	No. ¼ oval	70	do		
		64	(602 × 403)	195	242		

Coho	do					9 to 10 fish per case	Is not very abundant. Forms only 7 per cent world's pack canned salmon. More important in fresh, frozen and smoked fish trade.
Pink	do					17 fish per case	Smallest and most numerous of salmon. Forms 41 per cent world's pack.
Chum	do					9 to 10 fish per case	Has less color in flesh and lower oil content than other species so is not as popular. Sells at lower price than other species salmon but has very high food value and can be made into palatable and nutritious dishes.
Sardines:							
California	2 oz. tomato or mustard sauce to each 1 lb. oval—1 oz. to each ½ lb. oval or 8 oz. rect.	16 16 9 8	No. 1 tall No. 1 oval ½ rect. } ½ oval }	75 65 50	240 240 240	Average of 13 cases of sardines per ton of fish required by Calif. law. Fish in good canning cond. about 20 cases to ton.	Packing of natural and smoked fillets becoming important feature of pack.
Maine	Cottonseed oil	3½ 11	(quarter oil) (¾ mustard)	45 60	240 240	20 cases per hogshead (large fish); 30 cases per hogshead (small fish).	Maine law requires; use of winter-pressed cottonseed oil 4 lb. per case (100 quarter); minimum of 4 fish per can (keyless), 5 (keyopening).
Mackerel:							
Boston	3%	14 14 16	1 lb. oval 1 lb. tall No. 2 short	75	240	66%	Declared net weight on 1 lb. ovals 12 oz., but fill is always heavier. Mackerel must be firm and not over 24 hrs. old.
California	3%	17⅝ 17 11½	No. 1 tall (301 × 411) No. 1 meat (301 × 407) No. 1 standard (211 × 400)	9 75 75 75 60	240 or 250 250 240 or 250	No data	Some mackerel packed raw without brining, ¼ oz. salt added to can. Not recommended by canning technologists who urge brining be employed.

* The fill given is actual weight filled into container and should not be considered recommendation for declared weights to be used on the label of the container.

TABLE 98. CANNING OF FISHERY PRODUCTS—CONDENSED PROCEDURES AND PACKING DATA. (*Continued*)

Product	Brine or sauce	Fill *: Weight	Fill *: Can size	Process: Time	Process: Temperature	Yield	Remarks
		Ounces		*Minutes*	*Deg. F*		
Tuna:†							
Albacore	oil and salt	9 1/8	8 oz. (211 × 304)	75	250		Small amounts of tuna packed in glass tumblers, aluminum cans. Number of specialty tuna packs of which "tonno" is probably most important. Other specialty packs "ventresca," creamed tuna, garlic flavored tuna. Bonito also packed tuna style but may not be labeled as tuna yellowtail packed tuna style, but may not be labeled tuna. Some canned tuna imported into U. S. from Europe packed in salt brine without oil must be labeled "Packed without oil and in salt solution."
	oil 3/4 oz.; salt 1/14 oz.	3 1/2	No. 1/4 tuna	65	240	76 cases; 48/1/4s per ton	
	oil 1 1/2 oz.; salt 1/7–3/14 oz.	5 1/2–5 3/4	No. 1/2 tuna	75	240	47 cases; 48/1/2s	
Bluefin	oil 2; salt 9/14	11–11 1/2	No. 1 tuna	95	240	23 cases; 48/1s	
Yellowfin	oil 9; salt 6/7	46	4 lb. tuna	230	240		
Striped							
Alewife or river herring.	3%	16	No. 1 tall	50	244	No data	Labeled "fresh river herring" but is of canned salt-fish style. Fish wrapped individually in parchment paper and packed in No. 2 tall cans.
		26	No. 2 tall	60	250		
Fish flakes (haddock)	None	7 1/4	(211 × 300)	55	240	66 cans per 100 lbs. (211 × 300) size; 40 cans (307 × 208) size per 100 lb.	Fillets sometimes used instead of whole fish. Cod may be mixed with haddock 1 to 3, but is not often packed alone because of its soft texture.
		12	(307 × 208)	75	240		
Finnan haddie	None	4	(211 × 109)	55	240	About same as fish flakes not definitely determined.	Also packed in "nappy" glass tumblers. Imports from England in 1 lb. oval cans.
		12	(307 × 208)	75	240		
		16	(300 × 307)	75	240		
Shad	1/2 oz. salt	16 1/2	No. 1 tall	90	240	75 lb. round—fish per case 48/1s.	Pack resembles salmon, but flesh is rather dark and soft. Some kippered shad also canned.
Clams:							
Razor	Clam juice	5 1/4	No. 1/2	45	220	1 bu. clams = 40 No. 1/2 flat cans or 20 No. 1 tall.	Sold mostly as "minced sea clams."
		7 1/2	No. 1 picnic	45	220		
		12 1/2	No. 2	60	220		
Soft	3%	6	No. 1 picnic	20	240	48 No. 1 picnic cans per bu.	Darkening is principal difficulty in canning. If this occurs blanch in 1.5 per cent citric acid and add 0.5 per cent citric acid to pack.
		10	No. 1 tall	20	240		
		11	No. 300	20	240		
		12	No. 2	25	240		
Oysters:							
Atlantic or Gulf	4°	3	(211 × 300)	8	250	20 to 25 No. 1 picnic (211 × 400) cans per bbl.	1 bbl. = 3 bu. in Miss.; 1 bbl. = 4 bu. in La.; Miss. bu. = 2826 cu. in.; La. bu. = 2150 cu. in.; Std. U. S. bu. = 2150 cu. in. 9/0 loss = shell, mud, oyster juice (nectar).
		4	(211 × 304)	do	do		
		5	(211 × 400)	9	250		
		8	(307 × 400)	10	250		
		10	(307 × 409)	do	do		

Pacific	3%	7 to 9	No. 1 picnic (211 × 400)	29	240		Pacific oysters filled by count as well as weight. Certain number oysters must go into can for each grade size. Count per No. 1 tall can usually 6 to 7 if oysters are large, 8 to 14 if grade is medium, and 15 to 20 if grade is small.
		10 to 13	No. 1 tall	35	240		
		14 to 16	No. 2	42	240		
Crab (Dungeness)	4°	6½	(307 × 202½)	70	228	20 lb. meat or 4 doz. crabs to case 48/½s.	Dry salt may be used instead of brine. Speedy operation without delay, esp. important in this pack.
		13	(401 × 211)	80	228		
		17	(307 × 408)	80	228		
King crab (Japanese)	See remarks	3½	(211 × 109)	80	220	No data	2 oz. weak buffer sol. of organic acid (lactic or citric) added when discoloration may occur.
		6½	(307 × 202½)	90	220		
		13	(401 × 211)	80	228		
Shrimp	4°	5⅜	No. 1 picnic and squat.	10	250	190 No. 1 picnic cans per bbl. (210 lb.).	Processes for dry pack increase as liner type changes from 3 pc. to 1 pc.
		9¾	No. 1½	12	250		
		5⅛	No. 1 picnic and squat.	70 to 85	240		
		9¼	No. 1½	75 to 90	240		
Clam chowder	Hot soup added	4 solids, 6 soup	No. 1 picnic	60	240	550 No. 1 picnic to 168 lb. solid ingredients.	Down East clam chowder similar to Manhattan, except D.E. has whole clams, no tomatoes, and flour instead of cracker meal.
		7.5 clam, 7.5 potato, 11 soup	No. 3	85	240		
Fish chowder	Hot soup added	2 fish, 2 potato, 6 soup	No. 1 picnic	60	240	550 No. 1 picnic to 168 lb. solids.	Darkening or discoloration principal difficulty to be guarded against.
Fish cakes	Solid pack	10		75	240	460 cans to batch (200 lb. potato, 100 lb. fish).	Green Mountain potatoes best variety in fish cakes. Discoloration caused by over-processing.
Fish roe:							
Alewife (river herring).	3% (sometimes hot water used).	8	(211 × 300)	50	240	1 case 48/8 oz. cans per 20 lb. bucket "green" roe.	From 13½ to 15 oz. green roe required as fill in weight to give drained weight 16 oz. Variation depends on condition of roe.
		16	(307 × 400)	60	240		
"Deep sea" (Cod and haddock).	3%	14	(300 × 407)	75	240	400 cans to 300 lb. roe	Fill of cans must be watched carefully. Leave ½ in. head space in filling.
Shad	¼ oz. salt	7¾	½ oval	110	230	26; 6 lb. per case 24/½ ovals.	Roe must be fully developed but not over ripe. If roe is too ripe, is watery and lacks flavor. If too green is hard and tough.
				55	240		
				90	240		

* The fill given is actual weight filled into container and should not be considered recommendation for declared weights to be used on the label of the container.
† The season given applies only to California. Tuna of the various species are found on some part of fishing grounds throughout the year.
Source: Jarvis, N. D., "Principles and Methods of the Canning of Fishing Products," U. S. Fish and Wildlife Service, *Research Rept.*, 7 (1943).

REFERENCES

Anon., "Canned Food Reference Manual," 230 Park Avenue, New York, American Can Co., 1947.

Anon., "The Tuna-Fishing and -Packing Industry of California," Los Angeles, California, William R. Staats Co., 1949.

Beard, H. R., "Method of Preparing Fish for Canning," U. S. Pat. 1,553,296 (1925).

Cameron, E. J., and Williams, C. C., "Procedures in Shrimp Canning That Will Eliminate Spoilage," *Canning Age,* **15,** No. 10, 443–445 (1934).

Cameron, T., "New Hydra-Vac Lift Speeds Fish Direct from Boat to Cannery," *Food Industries,* **21,** No. 11, 92 (1949).

Clough, R. W., and Clark, E. D., "Salmon Inspection," *Am. J. Public Health,* **24,** 1252–1258 (1934).

Croker, R. S., "The California Mackerel Fishery," Calif. Division of Fish and Game, *Fish. Bull.,* **40** (1932).

DeLoach, D. B., "The Salmon-Canning Industry," *Oregon State Monographs, Economic Studies,* **1** (1939).

Federal Trade Commission, "Trade Practice Rules for the Tuna Industry," Washington, D. C., 1940.

Fellers, C. R., "Bacteriology of canned salmon," *Ann. Repts. Pacific Fisheries Investigations,* Nat'l. Canners Assn. 1920, 1921, 1922.

Fellers, C. R., "Nongaseous Spoilage in Canned Marine Products," *Univ. of Washington Publ. Fish.,* **1,** No. 11, 229–238 (1927).

Godsil, H. C., "The High-Seas Tuna Fishery of California," Calif. Division of Fish and Game, *Fish. Bull.,* **51** (1938).

Hamm, W. S., "Some Observations on Fish Processing in Norway," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **9,** No. 5, 12–15 (1947).

Hamm, W. S., and Rust, W. A., "The Electrostatic Smoking of Sardines," U. S. and Wildlife Service, *Fishery Leaflet,* **270** (1948).

Havighorst, C. R., "Machine Forms, Cuts, Puts Tuna in Cans," *Food Industries,* **21,** No. 12, 1767–1768 (1949).

Hunter, A. C., "Bacterial studies of salmon," *J. Bact.,* **5,** 353–361, 543–552 (1920); **7,** 85–109 (1922).

Hunter, A. C., "A comparative study of spoilage in salmon," *Am. Food J.,* **17,** No. 9, 19 (1922).

Hunter, A. C., "Sanitation in the Fish-Canning Plant," *Fishing Gazette,* **51,** No. 1, 19–21 (1934).

Jarvis, N. D., "Principles and Methods in the Canning of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.,* **7** (1943).

Lang, O. W., Farber, L. A., and Yerman, F., "The Temporary Holding of Sardines by Refrigerated Brine," Univ. of California, Berkeley, California, Hooper Foundation, 1946.

National Canners Association, "Processes for Nonacid Canned Foods in Metal Containers," *Bull.,* **26–L,** Washington, D. C., 1939.

Roedel, P. M., "Tuna-Canning Methods in California," *Calif. Fish and Game,* **24,** 251–272 (1938).

CHAPTER 21

Miscellaneous Processes of Preserving Fish

Variety of Products

The principal processes of fish preservation are canning, salting, smoking, and drying; in fact, in the United States few fish are preserved by other means. In Maine some herring are lightly salted and then pickled in a brine containing vinegar according to a process generally known as marinating. These fish are sold chiefly to Europeans living in New York and other large cities. Recently, many novel canned fishery products have appeared on the American market, but the primary means of preservation is sealing in tin or glass and subsequent sterilization (canning). These products are considered in the section on canning of fish (Chapter 20).

But in Europe, where the inhabitants are more dependent upon food from the sea, vinegar, spices, and other preservatives are commonly employed for the preparation and preservation of various fishery products. To obtain finely flavored products vinegar is often used in combination with salt, spices, etc. Fish are often fried in oil before being preserved in spiced vinegar. Slightly salted fish are sometimes preserved in vinegar. Meatless sausage is made by substituting fish for meat.

Since fish are one of the most common articles of diet in Japan and the Philippine Islands, they are preserved in almost every conceivable manner. Various fermented products, such as bagoong, are prepared. Fish are pickled in hot pure or spiced vinegar, without salting. The flesh of sharks is utilized for the preparation of an edible paste. Fish puddings are prepared, and are often flavored with alcoholic liquors.

Many of these unusual products might be successfully introduced in the United States. Some of them are sold in small quantities in several cities where the foreign population is very large. The difficulty of establishing a market among native Americans lies in the cost of an advertising campaign of sufficient extent to familiarize the public with the value of novel products.

Fish Pickled in Vinegar or Marinated

According to the common usage of the term, "marinated" fish are those which are soaked in vinegar sauce. The fish are prepared for the vinegar pickle either by baking and frying or by salting in either salt brine or brine containing some vinegar. In southern Europe marinated fish are fried in hot oil and packed in spiced vinegar. Although some marinated fish are packed in the United States and Great Britain, the industry is centered chiefly in Continental Europe, especially in Germany.

The finest German marinades formerly came from Stralsund, Rugen, and Danzig along the Pomeranian and Prussian coasts. Important marinade factories

were located in Berlin, Altenburg, Krefeld, Cologne, Bohmen, Geestemunde-Bremerhaven, and Hamburg-Altona. The principal raw material used in Germany for marinating is herring, although haddock, anchovies, and other fish are used to a limited extent.

Principle of the Use of Vinegar. Acetic acid is the active principle of all vinegars and the component which gives them their antiseptic properties. Vinegars differ from each other in flavor, color, and aroma because of the presence of small amounts of other organic compounds whose nature depends upon the source of the vinegar. The higher the percentage of acetic acid, the greater the preservative power of the vinegar; about 15 per cent of this acid is required to stop bacterial growth. Since only the very strongest vinegars contain this much acetic acid, it is evident that weaker vinegars are not able to preserve fish indefinitely in open containers. However, vinegars containing 5 per cent or more of this component will retard spoilage for weeks and perhaps months if the fish are kept in cool rooms.

Russian Sardines. A considerable quantity of small sea herring or Russian sardines is prepared in Germany, Russia, and to a small extent in America by first salting the fish in strong salt brine, then cleaning and pickling them in spiced vinegar. The small, fresh round herring or sardines are placed in saturated salt brine for about 10 days, or until they are thoroughly salted. The salted fish are then beheaded, eviscerated, and washed in fresh water. After draining, the cleaned fish are sorted for size; the various sizes are then packed separately into kegs or other containers. After various spices, such as allspice, chile pepper, cloves, ginger, coriander seed, and capers, are added, the kegs are filled with vinegar. Bay leaves, onions, and horse-radish are also used to flavor the pickled fish. The materials recommended for preserving 120 pounds of fish by this method are: vinegar, 2 gallons; allspice, 1.5 pounds; sliced onions, 4 pounds; sliced horseradish, 2 pounds; bay leaves, 2 pounds; cloves, 0.5 pound; ginger, 0.5 pound; chile pepper, 0.5 pound; coriander seed, 0.5 pound; and capers, 2.5 ounces. Fish prepared in this manner should be kept for a week to a month before being marketed. Such pickled sardines will keep for a year or more if stored in a cool place.

Fried Marinated Fish. A considerable quantity of fish are preserved in Europe by first being fried in oil and then marinated. Young herring, sardines, anchovies, or any small food fish may be preserved by this process. The fish are cleaned, washed, and then dried for about an hour in the open air. After drying, the small fish are fried in hot oil, cooled, and allowed to drain. The fried fish are packed in barrels, kegs, glass jars, or other containers and covered with hot spiced vinegar containing some salt. After standing for a short time the containers are closed and the fish are ready for shipment. Fish preserved in this way will keep for a long period if strong vinegar is used for preparing the pickle.

Bismarck Herring. True marinated fish, according to the Germans, are those which are cured with strong salt and vinegar pickles, without being cooked. Examples of the German products are Bismarck herring, mustard or Kaiser-Friedrich herring, and Russian sardines. The most important of these are Bismarck herring and Russian sardines. A few American packers have realized the demand for these products and have packed limited quantities, but the chief industry is in Germany and the U.S.S.R.

In Germany Bismarck herring are prepared from herring of a uniform size. The

fish are first washed in a special washing machine consisting of a large revolving drum equipped with a spray of water. The washed and scaled fish are then cleaned, beheaded, and boned by women. The boned fish are rinsed with water and brushed inside to remove the black lining of the belly cavity. The cleansed fish are then placed in salt brine for 2 or 3 hours. The slightly salted fish are put into a vinegar pickle (from 5 to 6 per cent acetic acid) containing a moderate amount of salt. After remaining in the pickle for 2 days the fish are removed and placed on large tables in the work room, where they are packed tightly in boxes with a slice of onion and some pepper and mustard seed. After a vinegar sauce (from 2.2 to 2.4 per cent acetic acid) containing some sugar is added, the box is closed and wrapped. The herring are usually shipped immediately, but if stored they are kept in cool, dry rooms.

Mustard or Kaiser-Friedrich herring are prepared in exactly the same manner as Bismarck herring; however, a mustard sauce, instead of sweetened vinegar, is added when the fish are packed. The mustard sauce is usually prepared in special factories and is merely thinned preparatory to use in the marinating factory.

Other marinated fish are prepared by the addition of Remoulade, wine, bouillon, tomato, or Cumberland sauce to the vinegar-prepared fish. Sauce prepared from the milts of herring constitute another favorite marinade. In cutting the herring the milts are collected and mixed with vinegar sauce. When desired for use the milts are strained through a sieve so that the membranes are removed. As the herring are packed in boxes, black pepper, pimento, onion, clove, bay leaf, and other spices are sprinkled over each layer, the combination of spices used depending on the individual taste of the packers. The milt sauce is added to the packed and spiced vinegar-prepared fish. The boxes of herring are then closed and wrapped in the same way as plain Bismarck herring.

The marinated product, rollmops, is prepared by rolling the boned and vinegared herring with a slice of cucumber pickle or onion. The roll is fastened on two sides with a small wooden pin or "skewer." These rolls are packed in boxes and covered with cucumber pickle, shallot, bay leaf, paprika, pepper, pimento, and mustard seed. Vinegar is finally added, and the box is covered and wrapped. When fresh herring are very scarce or costly, rollmops are prepared from salt herring. In this case the salt fish are freshened, washed, and boned, and then placed in the vinegar pickle, which need not be as strong as when fresh herring are used since the fish are already cured. Salt herring usually make an inferior quality of marinated product.

Japanese Pickled Fish. The Japanese pickle fish by a very simple process. The fish are merely cleaned, washed, and then placed in jars or kegs and covered with either pure or spiced vinegar at or near the boiling point. To keep such fish in warm weather they must be either pickled with very strong vinegar or kept in cold storage.

Fermented Fish Products

Fermented bagoong is one of the most common fish products of the Philippine Islands. The native process of manufacture may be as follows: Two parts of anchovies or other small fish are mixed with 3 parts of salt. This mixture is placed in stone jars, covered to exclude flies and dirt, and allowed to ferment for 1 month. The liquid portion is used as a sauce and the solid is fried or mixed with eggs.

Fish Sausages

In Germany, Norway, Denmark, and other countries of northern Europe sausages are prepared in large quantities from mixtures of fish, fish liver, seal meat, crab meat, fish roe, pork, flour, and various condiments, and sold as different kinds of fish sausage. The flesh of the fish, crab, etc. is ground finely with pork, flour, and spices, and the product is either canned with sauce or stuffed into sausage casings. It is either sold raw or smoked. In some cases no fresh fish flesh is used in the manufacture of these sausages, and salted fish, dried fish, fish roe, fish liver, and the like are substituted. Other ingredients occasionally used in the preparation of these sausages include oysters, mussels, and other shellfish.

Several attempts to introduce fish sausage in the United States have met with only moderate success, and this has been confined to delicatessen trade. Each operator has developed his own formula for the ingredients included, and they have been rather reticent about disclosing them. Some operators have indicated that they use only steamed or boiled fish flesh with the bones removed. The fish flesh may be entirely of 1 species or a mixture of several. The prior cooking removes a considerable portion of the water and gives a more solid sausage. Salt, spices, and some type of filler, such as corn meal, wheat, or soy flour, are added. The ingredients are then thoroughly mixed and stuffed into one of the several types of sausage casings. The proportions of the ingredients and time of smoking vary with the individual operator. Some operators smoke the encased sausage for 1 or 2 hours. Sausage prepared in this way will keep under refrigeration for periods as long as 3 weeks.

Fish sausage is being produced to some extent in the Canadian Maritime Provinces. The methods are similar to those previously described. Each operator has developed his own formula as to spices, but fillers of cereal are commonly used. In some instances the producer includes a fish stock made by cooking at a low simmer the heads, bones, and skins. This is boiled down to a liquor and added to the sausage mixture. Some producers smoke the sausage; others do not.

Within recent months a new type of sausage, prepared from East Coast tuna and packed in frankfurter casings, has been introduced to the market by one New England fish packer. This sausage is given the name "Friday Franks," and is intended to compete with the well-known "frank" made from meat. This sausage contains a cereal binder, spices, and salt. It is marketed under refrigeration for home cooking or processed in tin cans.

Anchovy

Anchovy Paste. Anchovy paste is another European product of much importance. Saltpeter and salt are the chief preservatives used in its preparation. It may be made from a peck of anchovies by the following method: Grind together 2 pounds of common salt, 3 ounces of bay salt, 1 pound of saltpeter, 2 ounces of sal prunella, and a few grains of cochineal. Then put a layer of fish into a stone jar and cover with the ground mixture, and so on until the jar is filled; press them down hard and cover closely. After 6 months they will be ready for use.

Christiania Anchovies. Christiania anchovies are prepared by packing slightly salted fish in spiced brine. The fresh sprats are immersed in weak brine for 12 to 18 hours, about 15 pounds of salt being used for each 100 pounds of fish. At the

end of this period the fish are drained and loosely packed in a barrel with the following ingredients, which have been previously finely crushed and well mixed: 4 pounds of Luneburg salt, 6 units of pepper, 6 units of sugar, 6 units of English spices, 1 unit of nutmeg, and 1 unit of Spanish pepper. After 2 weeks the anchovies are repacked tightly in barrels or kegs by being carefully arranged in layers with backs downward. A quantity of the ingredients mentioned and a few bay or cherry leaves are sprinkled over each layer. The barrels or kegs are filled with brine and then coopered; they are turned daily for the first few days and then every other day for 2 or 3 weeks.

German Delicatessen (Anchovies). In Sweden, Finland, and Germany many anchovies and small herring are preserved by packing in salt and sweetened and flavored with sugar, saltpeter, pepper, cloves, mace, cinnamon, ginger, sandalwood, Spanish hops, bay leaves, etc. In Finland the sprats or anchovies are thoroughly washed and packed in the round, but in Sweden the fish are eviscerated, beheaded, and thoroughly cleaned.

The procedure in packing the fish is usually about as follows: Salt, sugar, and saltpeter are first weighed out and thoroughly mixed together, then the other ingredients are weighed and mixed accordingly with the salt and sugar. Some of the spice mixture is strewn on the bottom of the 1-liter tin. A layer of herring is then placed, backs downward and in rows, in the tin, and the spice mixture is strewn over it. Another layer of herring is laid down in the same way, the rows being placed obliquely across the rows in the layer below, and so on until there are 4 layers in the tin. One bay leaf is placed at the bottom, 1 between each layer, and 1 on the top. The lid is then put on and, for local use, made airtight with paraffin. The closed tins are stored in a cool place, preferably in a refrigerator.

A few preservative and spicing mixtures recommended for use in preparing German anchovies are given in Table 99.

TABLE 99. SALT, SPICE, SUGAR MIXTURES USED IN PREPARING GERMAN ANCHOVIES.

Mixture	*A* G. per liter tin	*B* G. per liter tin	*C* G. per liter tin
Luneburg salt	125–150	150	
Liverpool salt			150
Sugar	50	100	100
Saltpeter	1.5	2	
Jamaica pepper	3.5		4
Black pepper	1	2	3
Cayenne pepper			0.04
Cloves	1.5	1.5	2.0
Mace	1.0		1.0
Sandalwood		1.0	1.0
Cinnamon	0.5		1.0
Ginger	0.5	1.0	2.0
Spanish hops		1.0	2.0
Bay leaves	1.5	2.0	2.0

Anchovies are usually packed in kegs, but cans are highly recommended. Only the fatter fish are used as lean fish yield an inferior product.

Caviar

U. S. Processes of Manufacture. Caviar in the strictest sense of the word is the prepared roe of various species of sturgeon. Recently, roe of various other species of fish has been used for making caviar since the supply of sturgeon roe has diminished to the point where it is entirely inadequate to meet the demand. Other species of fish whose roe are sometimes used for making caviar include spoonbill cat or paddlefish, salmon, whitefish, lake herring, carp, and cod.

Only a comparatively few years ago sturgeon was a very common fish in American waters. However, when caviar and smoked sturgeon became popular, the price of these products rose rapidly and fishermen found sturgeon fishing a profitable occupation. As a result the waters were overfished, and now sturgeon is practically nonexistent. Because of the scarcity of these fish only a limited amount of caviar is prepared in the United States. In most cases the fisherman who catches the female sturgeon prepares the caviar and sells it either to the local buyer or to a buyer in a nearby wholesale market.

In preparing caviar the sturgeon roe, immediately after its removal from the fish, is placed on a 4-mesh sieve over a large mixing tub. The roe is rubbed back and forth on the sieve until the eggs pass through, leaving behind membranes and connective tissue. About 1 pound of Luneburg salt or ½ pound of American dairy salt is sifted over each 12 pounds of eggs. Luneburg salt is a German salt that has a flavor which is particularly complimentary to caviar. Immediately after the addition of the salt the mass is thoroughly mixed. At first the mass is sticky, but enough water is soon abstracted from the sturgeon eggs to dissolve the salt and form a brine. The mixing is continued for 5 to 8 minutes, after which the mixture is allowed to stand 10 minutes or longer. The eggs are then poured into sieves, having a capacity for 8 to 10 pounds of caviar, and allowed to drain for about an hour. The caviar is poured into kegs and shipped to the canning factory where it is placed in cans or jars which are sealed and pasteurized.

A method for pasteurization, described by Levine, Fellers, and Barton (1949), recommends immersion of the caviar in a hot-water bath at 155 to 160° F (69 to 71° C) for 30, 45, and 60 minutes for 1-, 2-, and 4-ounce containers, respectively. This treatment makes it possible to store caviar at temperatures as high as 60° F (15.5° C) for several months without off flavors or decomposition resulting.

Caviar Manufacture in Russia. The preparation of caviar is a matter of much importance in Russia. The most highly prized caviar is made from sturgeon roe. Since the sturgeon fisheries of Russia are much greater than those of the United States, more sturgeon caviar is prepared in that country. Roe from the pike perch (*Lucio perca sandra*), the Caspian roach, and the bream are also extensively used for a preparation known as scaled-fish caviar. The methods used in Russia are much the same as those employed in the United States, except that comparatively little is canned and much is prepared especially for export by pressing. Pressed caviar contains less water than the ordinary product, and consequently keeps better.

Fresh-Grain Russian Caviar. Fresh-grain caviar is prepared in Russia from the full roe of the female sturgeon. After killing, the fish is placed on a coarse mesh screen spread across a wooden tub. The roe is removed by splitting the belly of the sturgeon with a sharp knife. The roe is gently rubbed through the screen with the palm of the hand. This separates the eggs from the binding tissue, and they

drop into the tub below. After a portion of the eggs have collected in the tub, they are put into a bucket and the process is repeated. Considerable care must be taken in rubbing the eggs through the screen since bruising them results in very poor caviar.

When all of the eggs have been passed through the screen into the tub, those removed from the tub into the bucket are returned to the tub. Dry salt in the proportion of 1 pound to 9 pounds of roe is added. In the early spring or late fall the proportion of salt is changed to 1-part salt to 36-parts roe. The salt is mixed thoroughly and gently with a wooden paddle for 5 to 8 minutes. It is then placed on a fine mesh screen to drain.

After the pickle or brine is drained, the caviar is packed in tin, glass, or porcelain containers, equipped with a tight fitting cover. The caviar is then ready to eat or store under refrigeration at about 41 to 46.5° F (5 to 8° C). When removed from refrigeration it must be eaten immediately as it will not keep. Caviar cannot be pasteurized or processed without damage.

Pickled Grainy Caviar. The type of caviar prepared for export is the pickled grainy variety. It is put through the first screen into a tub the same as fresh caviar. A saturated salt brine pickle is poured over the roe in the tub. The mixture is stirred until the individual eggs make a slight bumping noise. An experienced operator can judge when the caviar is finished by squeezing the individual eggs between his thumb and finger.

The eggs are drained on a screen and are ready for packing in containers similar to those used for fresh caviar. Salt imparts a sharper taste and a graininess to the pickled grainy caviar, and enables it to be stored at a slightly higher temperature as fresh caviar.

A third method is similar to the first two, except that the eggs are pickled longer. They are usually pickled so hard that they cannot be crushed with the fingers. The eggs are drained, put into cotton bags, and placed in a press. The excess liquid is squeezed out of the caviar, and it becomes a cake which may be sliced. Caviar in this form is considered a delicacy. The cakes are wrapped in oiled paper to prevent drying and stored in a cool room at a temperature of about 46.5° F (8° C).

Dried Mullet Roes. Dried mullet roes are prepared to a limited extent along the southeastern coast of the United States, from North Carolina to Florida. The unbroken roe bags containing the mullet roe are placed in tubs where they are either sprinkled with salt or soaked with brine. About 5 quarts of salt are added to each 100 pounds of eggs. Too much salt will cause the egg sacks to break. After the roes have remained in the salt or brine for 10 to 12 hours, they are drained and spread on boards in the sun to dry. They are taken in each night to prevent their becoming wet by dew. During fair weather the drying process requires about a week. The finished product varies in color from a yellowish brown to a dark red.

When the drying process is completed, the roe may be dipped in a mixture of melted beeswax and paraffin and held for a considerable period of time at room temperature. It can be kept for much longer periods under refrigeration at 40 to 50° F (4 to 10° C). The mixture of 50 per cent wax and 50 per cent paraffin prevents further loss of moisture in the preserved roe.

In some cases this product has been smoked with a cool smoke immediately after brining. Only a very light smoke is used for approximately 30 minutes at just

sufficient heat to burn the sawdust. This adds to the keeping quality and flavor of the final product.

Shark Products

Shark-Flesh Paste. Shark and dogfish are highly prized as articles of food in the Orient. The Japanese prepare an especially tasty dish from shark and dogfish flesh called shark-flesh paste. The flesh is freed from skin and bones and cut into shreds which are pounded with a wooden pestle in a wooden or stone mortar until they are reduced to paste. During the pounding a little salt and various other condiments are added; this practice varies in different parts of the islands. The paste is made into rolls upon a board much as butter or cream cheese is handled. The rolls are steamed over boiling water for 20 minutes in a closed oven. The product is white and has an attractive appearance; it will keep for several days, even in summer.

Preservation of Shark Fins. Shark fins are commonly used by the Orientals, particularly the Chinese, in the making of soup. Though classed as either white fins or black fins none of them is perfectly black or perfectly white. They are divided into several groups of different values, depending upon color, size, and variety. The chief commercial classes of fins are the following: white spotted fin (Chinese *boon leong sit*), graded into large and small white fins; large white fin (*chu sit*); small white fin (*peh sit* and *khiam sit*); large black fin (*tua sit*); small black fin (*oh sit* and *seow oh sit*); and small black-tipped fin (*oh ku sit*). In preparing fins for market they are merely cut from the shark; the cut portion is well salted or dusted with lime and dried in the sun.

Japanese Canned-Fish Pudding. The Japanese prepare an unusual product called canned-fish pudding by grinding and kneading the fish meat, which is seasoned with salt, sugar, and *mivin*, a liquor similar to vermouth. The pudding is placed on a wooden board and boiled or steamed, after which it is slightly baked before being packed in the cans and sterilized.

Herring in Sour Cream Sauce

There is some demand for herring in the pickled form in this country. This product is generally carried in delicatessens, and is kept in a cool, usually refrigerated, place.

In preparing these products there is quite a wide variation between specific recipes used by different packers, but in general the finished products are quite similar. The ingredients consist of dry white wine, sour cream, sweet cream, distilled vinegar, mixed spices, and sliced onions. Herring in wine sauce differ in the ingredients used in preparing the sauce, and are usually much more highly spiced than the cream sauce pack. Some packers prepare a herring salad and herring bits.

REFERENCES

Avery, A. C., "Cosmopolitan Fish Cookery for the Philippines," U. S. Fish and Wildlife Service (1949).

Burrell, J. R., "Acetic Acid Preserves," *Food Manufacture*, **23**, No. 8, 362–363 (1948).

Jarvis, N. D., "Principles and Methods in the Canning of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.*, **7** (1943).

Levine, A. S., Fellers, C. R., and Barton, R. R., "Preservation of Russian Caviar by Canning," *Mass. Agr. Expt. Sta. Contribution*, **719** (1949).

Sidaway, E. P., "Fish Pastes," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **63,** 38–40 (1945).

Sidaway, E. P., and Young, O. C., "Anchovy Products," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **63,** 41–42 (1945).

Sunderland, P. A., "Spiced Surf Smelts," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **37,** 17–18 (1938).

Watson, D. W., and Hess, E., "The Preparation of Marinated Herring," Canadian Biol. Board, *Prog. Rept. No. 18, Atlantic Station,* 3–6 (1936).

CHAPTER 22

Fish Meal and Oil

Introduction

The reduction of certain species of fish and waste materials from canning and filleting operations is not a recent development in the fishing industry. In early colonial days the need for fats and fertilizer led to the utilization of certain oily or fat species of fish. These products from the fishery resources were obtained by the most primitive methods; however, since then methods and equipment have been perfected and are now highly efficient and economical. At present the profit derived from the conversion of waste products into meal and oil in such operations as filleting and canning often represents the difference between a gain and a loss in the over-all operations of the processor. Methods of fish meal and oil production are usually based upon the quantity and quality of the material and the condition in which it is received at the by-products plant. Waste materials from the filleting of such nonfatty fish as cod and haddock are processed differently from those received from such oily fish as red perch and herring. The final decision regarding the method to be employed is made by the processor after an examination of several properties: the quantity of material available; the condition of quality (whether or not it is partially decomposed and how far this has proceeded); and the possible oil content.

Both the wet- and dry-reduction processes are in use. The former is by far the most commonly used in the United States and Canada. Dry reduction is generally more costly to install and operate for the same capacity, and the products obtained are often of inferior quality. Wet reduction is a continuous process and is adapted to large operations, such as the menhaden, herring, and pilchard industries.

Dry-Reduction Process

Fishery products to be reduced by the dry process consist principally of waste materials from the filleting of cod, haddock, and halibut heads. The carcasses of grayfish and shark are suitable for dry reduction because of the low fat content. Fish with a high fat or oil content are seldom reduced by this process.

When the material to be handled is delivered to the reduction plant, it is first put through a grinder or hogger. This serves to break up the large pieces and disintegrate the bones, thus facilitating drying. The ground mass is then loaded into a steam-jacketed dryer through a port at the top.

The drier is an apparatus composed of a cylinder within a cylinder, separated by a 1- to 3-inch space. A stirring mechanism is fitted through the axis of the apparatus to agitate the material to be dried in the inside cylinder. Live steam under pressure is admitted into the space between the two cylinders, and the mass is agitated by the stirring mechanism during the drying process. This insures a more even drying throughout the mass and prevents scorching. The inside

cylinder is loaded through the port to from ½ to ¾ of capacity with raw fish waste.

In some plants the port is covered and a vacuum is drawn on the inside cylinder to increase the rate of drying. In others the port is left open and the drying takes place under atmospheric pressure. If the latter method is used, the drying time is increased, with a corresponding increase in cost.

When the mass of fish has been cooked and dried sufficiently, as determined by the operator, it is discharged through a port at the bottom. This material is then placed in a hydraulic press where the small amount of remaining water and oil is pressed out. The cake of pressed meal is then ground, after which it is ready to be sacked for market.

Since fish meal prepared by this method contains all the water-soluble compounds, it may bring a higher price in the market. However, it also contains a larger per cent of oil which, in some markets, offsets the higher value of the meal. The oil produced by this method may be more highly oxidized and in general brings a lower price than oil produced by the wet-reduction process.

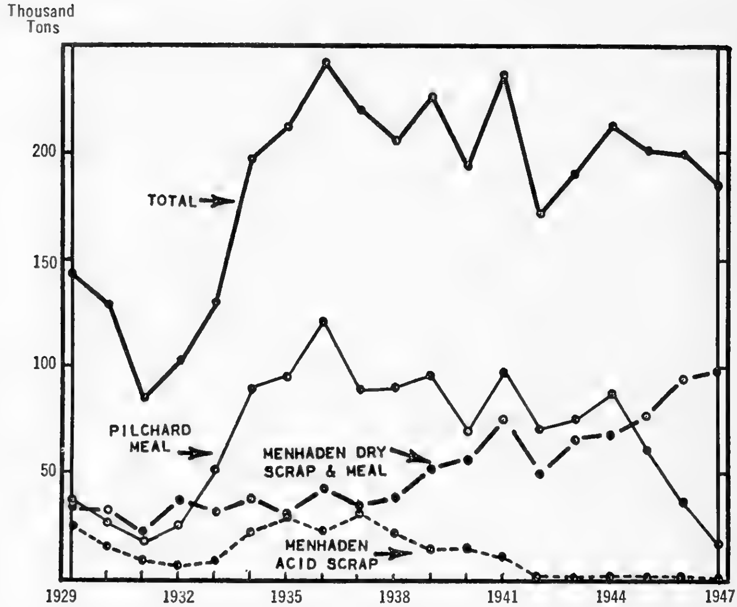
Butler (1949) states that equipment for setting up a dry-rendering plant, designed to process shark carcasses which contain no recoverable oil, costs approximately $35,500, plus freight from the manufacturing plant. These costs are calculated on the basis of a capacity of 32 tons of raw material per 12-hour day. This estimate includes the installation of four batch driers of the steam-jacketed type, conveyors, motors, grinders, and meal-collecting and sacking equipment.

It is further estimated that a similar unit, suitable for processing fish waste with a capacity of 1 ton of raw material per hour, consists of the same equipment, except that only one drier is included. The costs in this case are approximately $25,000, plus freight charges. This estimate does not include steam and electric power for operating the equipment. Boilers and fuel would be additional, and would probably cost about $1,200 to $1,800 for the 4-unit operation and about half that amount for the 1-unit plant. The fuel costs would depend upon the type of fuel desired for the plant operation. A supply of water for use in generating steam in the boilers would of course be needed for either of the above operations. Odor-disposal equipment is also required, especially in densely populated areas.

Wet-Reduction Process

Fish used in large volume for the production of oil and meal are reduced by the wet process. The three species of fish which are included in this group are the menhaden, pilchard, and sea herring. Menhaden is by far the most important, rated according to volume of catch. It is the only species which is considered unsuitable for human consumption, chiefly because of its excessive oil content. It is also the only species which is sought entirely for its value in the production of meal and oil.

At one time meal was considered the least valuable product from fish, and was used chiefly as fertilizer. Of late years meal has become recognized as an exceptional ingredient for animal food, and its value for this purpose exceeds that of oil. In 1948 there were 501,578 tons of menhaden manufactured into 104,058 tons of meal, valued at $11,560,914, and 8,763,939 gallons of oil, valued at $10,132,179. Menhaden is found on the Atlantic and Gulf coasts. A breakdown of the production of this industry by states is contained in Table 102 (p. 472).



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 22–1. The production of fish scrap and meal during 1947, amounted to 186,440 tons. The outstanding developments of 1947 were the continued decline in the production of pilchard meal and the continued rise in the output of menhaden meal. For the third successive year, the output of menhaden scrap and meal was greater than that of pilchard. Preliminary data indicate that the 1948 production of fish scrap and meal was three per cent greater than in 1947.

The quantity of fish oils, exclusive of liver oils, produced domestically during April, 1949, was 86,082 gallons, compared with 179,524 gallons extracted during the preceding April. Production of oil during the first 4 months of 1949 totaled 418,775 gallons, compared with 406,368 gallons during the same period of 1948.

The quantity of fish meal processed during April by firms that normally produce 92 per cent of the total yield amounted to 4,623 tons, approximately 300 tons less than was reported during April, 1948. During the first 4 months of 1949, 16,230 tons were produced, compared with 14,631 tons during the corresponding period of 1948.

The pilchard industry is located entirely on the Pacific Coast. This species ranges from San Diego to Vancouver, B. C., and the center of the industry is located in California. The State of California regulates the quantity of the fish which can be made into meal and oil by issuing licenses to the producers. The license states the specific tonnage that the producer may handle, and requires that a certain number of tons be canned from this tonnage; the remainder may be converted into meal and oil. These proportions vary from season to season, according to estimates of the prospective fish population. The production of meal from this species in

TABLE 100. UNITED STATES PRODUCTION OF MARINE-ANIMAL SCRAP AND MEAL, 1948.

The 1948 production of fish and marine-animal scrap and meal in the United States and Alaska amounted to 199,519 tons, valued at $23,086,734 to the producer. This was an increase of 7 per cent in volume and 3 per cent in value compared with the previous year. The production of menhaden scrap and meal, which exceeded 100,000 tons for the first time, accounted for over half the volume and value of the 1948 production. Due to the continued failure of the pilchard fishery in California, the yield of pilchard meal amounted to only 19,076 tons—only 16 per cent of the record 1936 production of 121,739 tons.

Product	Atlantic and Gulf Coasts		Pacific Coast (including Alaska) [1]		Total	
	Tons	Value	Tons	Value	Tons	Value
Meal and dried scrap:						
Anchovy			163	$21,517	163	$21,517
Crab, blue	5,151	$266,761			5,151	266,761
Fur seal			341	36,996	341	36,996
Groundfish ("white fish") inc. rosefish	21,780	2,872,544			21,780	2,872,544
Herring	4,632	431,221	13,054	1,633,821	17,686	2,065,042
Menhaden	[2] 104,058	11,560,914			104,058	11,560,914
Pilchard			19,076	2,614,616	19,076	2,614,616
Salmon			1,152	112,223	1,152	112,223
Shark	[3]	[3]	[4] 106	[4] 11,178	106	11,178
Shrimp	724	49,016			724	49,016
Tuna and mackerel			21,305	2,757,778	21,305	2,757,778
Whale:						
Meat	10	700	409	40,900	419	41,600
Bone			60	3,000	60	3,000
Miscellaneous	[5] 3,124	319,591	[6] 4,374	353,958	7,498	673,549
Total	139,479	15,500,747	60,040	7,585,987	199,519	23,086,734

[1] Includes small production of unclassified meal in Minnesota and shark meal in Florida.
[2] A small production of acidulated scrap has been included with dry scrap and meal.
[3] Included with West Coast production.
[4] Includes Florida production.
[5] Includes production of cod-liver press cake, fish pomace, and alewife, horseshoe crab, lobster, and miscellaneous fish scrap and meal.
[6] Includes a small production of unclassified meal in Minnesota, and dungeness crab and miscellaneous scrap and meal on the Pacific Coast.

1948 was 19,076 tons, valued at $2,614,616, and the oil production was 2,328,572 gallons, valued at $2,457,858.

Production of herring meal and oil is common to Alaska and to the Atlantic, Gulf, and Pacific coasts. In 1948 production of this species amounted to 17,686 tons of meal, valued at $2,065,042, and 3,631,815 gallons of oil, worth $3,992,854.

The greater portion of these three species of fish are caught by means of purse seines although some herring in Maine and the Chesapeake Bay areas are taken

TABLE 101. PRODUCTION OF MARINE-ANIMAL SCRAP AND MEAL, 1939–1948.

Year	Dry scrap and meal		Acid scrap		Total	
	Tons	Value	Tons	Value	Tons	Value
1939	210,249	$8,827,747	15,853	$265,850	226,102	$9,093,597
1940	177,724	7,562,288	15,520	271,533	193,244	7,833,821
1941	225,815	12,852,781	11,029	242,792	236,844	13,095,573
1942	168,486	11,545,239	2,594	80,520	171,080	11,625,759
1943	188,848	13,570,331	1,555	58,821	190,403	13,629,152
1944	210,225	15,131,918	2,922	111,104	213,147	15,243,022
1945	199,118	14,343,138	1,557	62,200	200,675	14,405,338
1946	197,599	20,360,943	2,022	78,475	199,621	20,439,418
1947	185,808	22,353,488	632	26,863	186,440	22,380,351
1948	[1] 199,519	[1] 23,086,734	[1]	[1]	199,519	23,086,734

[1] A small production of acidulated menhaden scrap has been included with dry scrap and meal.

Source: U. S. Fish and Wildlife Service.

TABLE 102. PRODUCTION OF MENHADEN PRODUCTS, 1948.

Receipts of menhaden by manufacturers of menhaden products in 1948 amounted to 1,007,888,840 pounds (1,504,311,700 fish). This was the largest recorded landings in the history of the fishery, and it is believed that it was the first time that the yield of these fish had exceeded 1 billion pounds. The production of menhaden dry scrap and meal, amounting to 104,058 tons, valued at $11,560,914, exceeded the previous record established in 1947. However, because of a lower oil content of the fish, the yield of oil, which amounted to 8,763,939 gallons, valued at $10,132,179, was less than in 1946. Menhaden dry scrap and meal is used in animal feeds and a portion of the oil is likewise used in feeds, however, the major portion of the oil is used in the production of soap, paint, linoleum, and in many other manufacturing industrial processes.

States	Menhaden utilized	Dry scrap and meal		Oil		Total
	Lbs.	Tons	Value	Gals.	Value	Value
New Jersey	162,046,000	17,119	$1,810,903	1,694,939	$1,807,915	$3,618,818
New York and Delaware	224,843,290	[1] 22,224	[1] 2,265,161	2,518,835	2,970,399	5,235,560
Virginia	152,744,590	16,086	1,853,922	812,764	1,131,540	2,985,462
North Carolina	198,270,420	20,939	2,546,596	1,304,732	1,355,009	3,901,605
Florida	80,276,720	[1] 8,410	[1] 988,374	274,859	301,684	1,290,058
Mississippi	68,636,140	6,780	797,413	779,810	883,028	1,680,441
South Carolina, Louisiana and Texas	121,071,680	12,500	1,298,545	1,378,000	1,682,604	2,981,149
Total	[2] 1,007,888,840	104,058	11,560,914	8,763,939	10,132,179	21,693,093

[1] A small production of acidulated scrap has been included with dry scrap and meal production.
[2] 1,504,311,700 fish.

Note: Menhaden products were manufactured in 3 plants in New Jersey, 6 in Virginia, 8 in North Carolina, 5 in Florida, 3 in Mississippi, 2 in Delaware, and in 1 plant each in New York, South Carolina, Louisiana, and Texas.

by means of weirs and traps and some pilchard on the Pacific Coast are caught with a lampara net. There are sectional differences in the operation of purse seines. Discussions of the different types of gear may be found in Chapter 13.

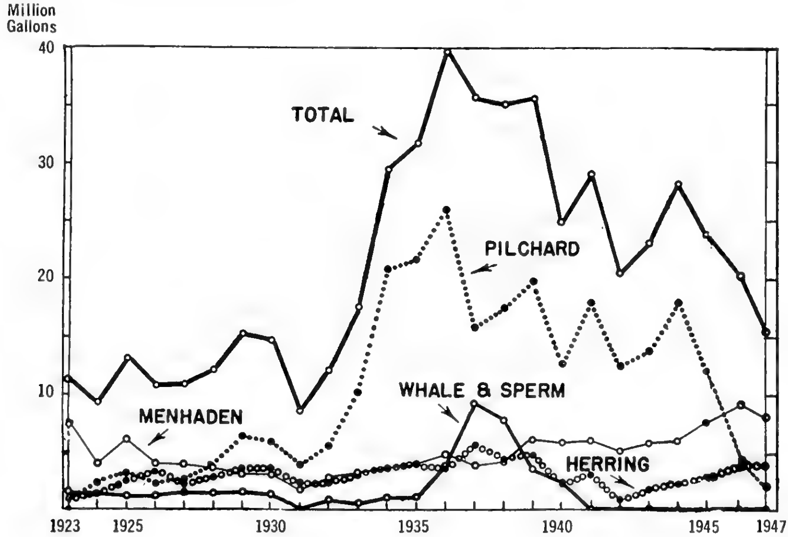
Since the wet process for the manufacture of fish meal and oil is very similar, regardless of the species of fish being processed, this discussion will be confined to the process in general and not to the handling of a particular species of fish.

TABLE 103. MENHADEN UTILIZED AND PRODUCTS OF THE MENHADEN INDUSTRY, 1939 TO 1948.

Year	Menhaden utilized	Dry scrap and meal		Acidulated scrap		Oil		Total
	Lbs.	Tons	Value	Tons	Value	Gals.	Value	Value
1939	514,135,800	52,950	$2,224,920	15,853	$265,850	6,005,414	$1,624,024	$4,114,794
1940	634,589,000	56,249	2,423,229	15,520	271,533	5,774,671	1,304,720	3,999,482
1941	775,086,820	75,316	4,008,355	11,029	242,792	6,034,050	2,829,441	7,080,588
1942	482,643,880	50,504	3,362,279	2,594	80,520	5,128,760	3,200,129	6,642,928
1943	615,554,460	66,357	4,766,672	1,555	58,821	5,734,668	3,892,142	8,717,635
1944	685,980,170	69,170	4,913,224	2,922	111,104	6,067,111	3,725,498	8,749,826
1945	759,073,820	77,451	5,483,377	1,577	62,200	8,335,094	5,656,550	11,202,127
1946	916,013,079	94,622	8,605,118	2,022	78,475	9,758,648	9,033,032	17,716,625
1947	948,155,592	98,602	10,883,852	632	26,863	8,473,371	11,425,497	22,336,212
1948	1,007,888,840	[1] 104,058	[1] 11,560,914	[1]	[1]	8,763,939	10,132,179	21,693,093

[1] A small production of acidulated scrap has been included with dry scrap and meal.

Source: U. S. Fish and Wildlife Service.



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 22–2. The production of fish and marine animal oils has shown a continuous decline since 1944, and a more or less general decline since reaching a peak of nearly 40 million gallons in 1936. The steady decrease during the past three years is primarily due to the failure of the pilchard fishery in California.

The domestic production of fish oil during April was less than that of a year ago, due to decreases in the quantity of tuna and mackerel and menhaden oils processed. Compared with April, 1947, the production of fish meal increased, with groundfish meal showing the major gain.

General Discussion of Process

Unloading the Vessel. All of the more progressive reduction plants unload the vessels by mechanical means. The most common of these is the bucket-type elevator which is lowered into the hold of the vessel. The fish are hoisted from the

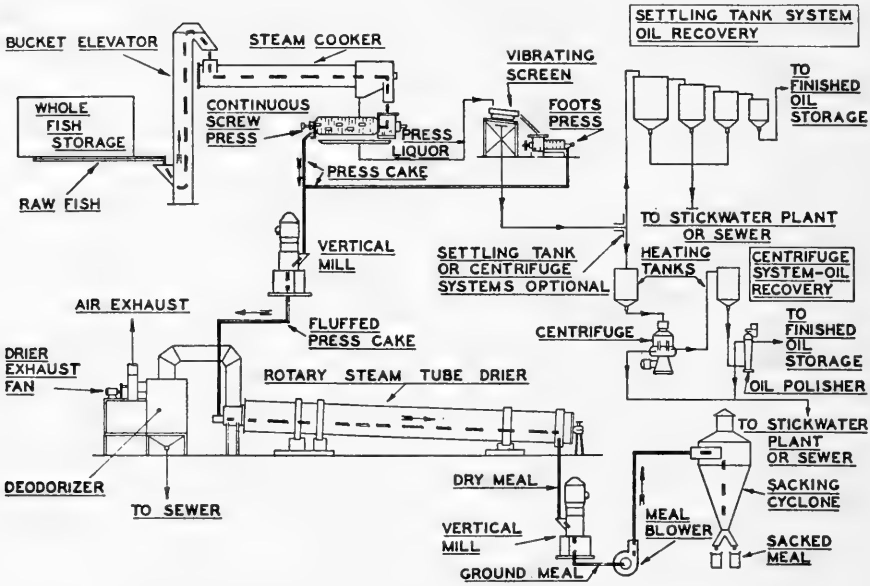


FIG. 22–3. Flow sheet for a typical fish reduction plant (wet method).

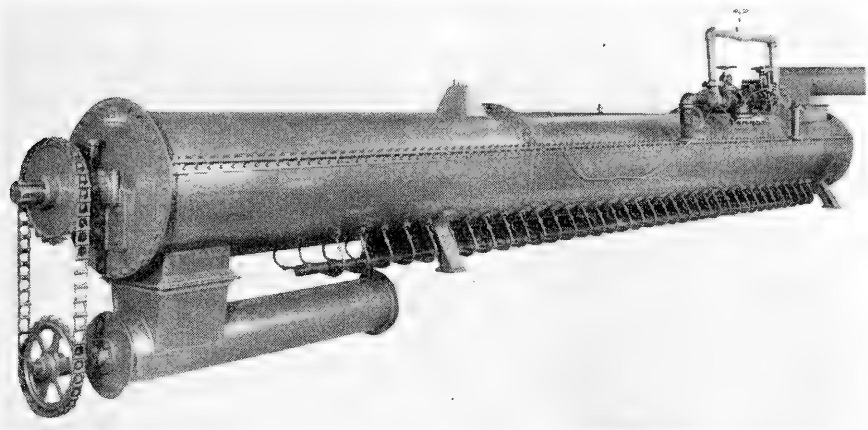
hold and deposited into some type of weighing mechanism. Within the last 3 years a centrifugal pump arrangement has been developed for pumping the fish from the hold of the vessel. This method of unloading is described more fully on pages 438 and 439.

The fish are mechanically conveyed from the weighing station to the plant and discharged into a large storage bin or "raw box." These bins are usually about 10 feet deep, but their length and breadth vary according to the capacity of the plant and the number and size of the cookers employed. The floor of the bin slants from both sides toward the middle where a screw-type conveyor is located. The conveyor is placed in a closed box with a cover which may be removed in sections as the bin is emptied. This screw conveys the fish from the "raw box" into the hopper, which feeds the continuous cooker. Its speed is regulated so that the fish will be fed into the hopper just as rapidly as they are passed through the cooker.

Continuous Cooker. Since it is desirable to cook the fish as soon as they are taken from the water, cooking is usually begun simultaneously with unloading. Stale fish putrefy quickly and are much more difficult to handle. Cooking breaks the fat cells so that oil is easily obtained when the fish are pressed.

The continuous fish cooker in general use today consists essentially of a stationary horizontal steel plate cylinder, from 16 to 30 inches in diameter and from 20 to 40 feet in length; this is fitted with an intake hopper at one end and a special discharge opening at the other. The lower portion of the cylinder is usually provided with several longitudinal rows of steam inlets or nozzles so placed that jets of live steam, under 5- to 10-pounds pressure, can be forced directly into the mass of fish moving slowly over the inner surface of the cooker shell. A hollow shaft, rotated by means of suitable gearing and supported in the two heads of the cooker, extends through the longitudinal center-line of the cylinder. Frequently,

this hollow central shaft is also provided with a series of steam nozzles; these are located between the turns of the conveying screw and are connected to a steam supply through stuffing boxes at its ends, which permits the injection of live steam directly into the upper part of the moving mass of fish. The speed of the screw can be regulated so that the conditions of cooking are adjusted to the fish.



(Courtesy Edw. Renneburg and Sons Co.)

FIG. 22–4. Continuous live steam cooker with feed screw, choke screw and thermal controls. This size cooker has a capacity of more than 15 tons of raw fish per hour.

This type of cooker has a smaller shell, about 8 feet long and 1 foot in diameter. The shell is attached to the discharge end, which is a little lower than the main cylinder and either at right angles or parallel to it. This is designed to keep the steam from escaping. After passing through the cooker the mass of cooked fish drops into the smaller cylinder and is carried through by a screw conveyor. A homogeneous and thoroughly cooked product, containing a 75 or 80 per cent mixture of water, oil, and fish protein, is thus delivered to the press by the cooker.

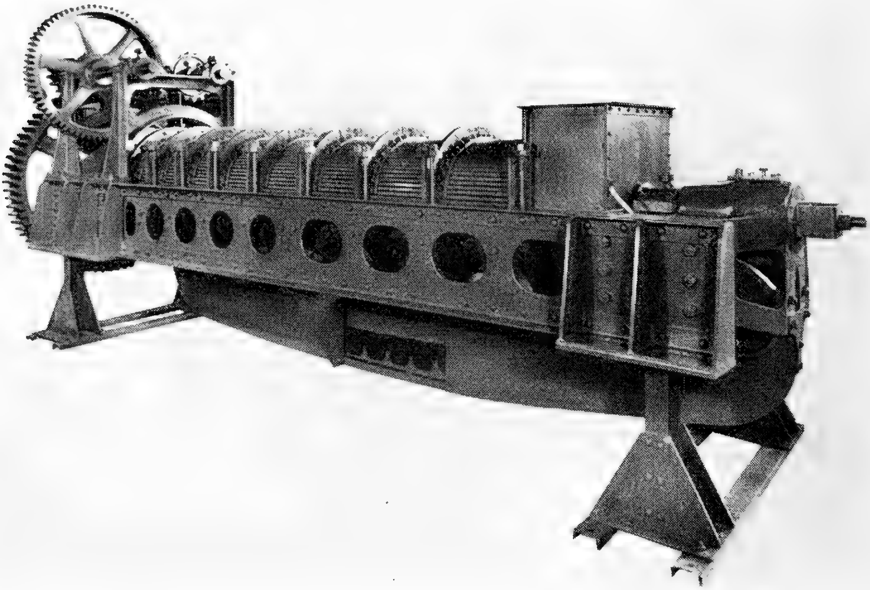
Continuous Screw Press. A common form of continuous press is composed of a heavy steel screw, enclosed in a cylindrical screen. The pitch of the screw flights become progressively smaller as it approaches the discharge end of the press. The cylindrical screen is heavily reinforced at frequent intervals. The screw is machined to fit closely into the cylinder, and is driven by heavy gears.

The hollow screw shaft is provided with a number of small steam nozzles between the convolutions of the pressing helix, and is fitted with a suitable stuffing box at each end for connecting up with a high-pressure steam supply. This arrangement permits jets of live steam to be forced directly into the cooked mass while under heavy pressure in the machine. Live steam serves to prevent clogging and likewise maintains the material at the necessary high temperature for maximum oil extraction during the pressing operation.

The discharge end of the machine is fitted with a special adjustable pressure-regulating device, by which the rate of discharge and the size of the outlet can be varied to suit the character and condition of the material being handled without stopping the press or interfering with its operation. This feature is of great

importance since the oil content of the fish and their age before processing largely determine the best method of handling.

The cooked fish pulp enters the press in a continuous stream directly from the cooker, and a thoroughly pressed and matted mass, called pressed scrap, is dis-



(Courtesy Edw. Renneburg and Sons Co.)

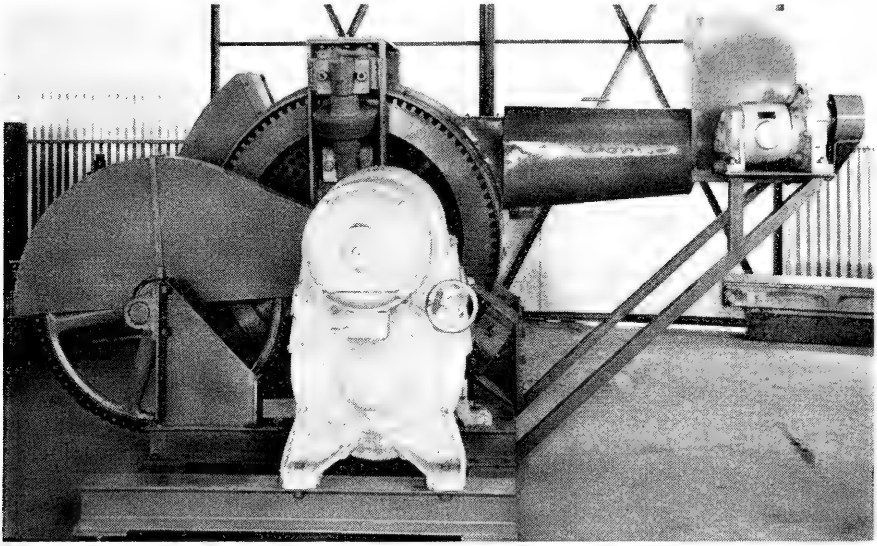
FIG. 22–5. The continuous screw press for squeezing the water and oil from the cooked fish.

charged at the opposite end. The intense pressure to which the material is subjected during its passage through the machine results in an expulsion through the screen openings in the cylinder of the press of most of the water and oil containing some small particles of protein. This liquid material is caught in a receiving pan located directly under the press.

Continuous De-watering Press. A continuous-type press of entirely different design from those used previously has been manufactured within the last few years. This press requires less floor space and is equal or better than the screw press as regards efficiency of operation. It is composed of two wheels, approximately 4 feet in diameter and set at an angle from the vertical on the shaft. The angle is adjusted so that the greatest pressure on the material between the wheels occurs slightly before the bottom point of their rotation. The angle of these wheels is set so that they form a "V." The wet material to be pressed is fed in at the top of the "V." The pressure is increased as the wheels approach the nearest point of contact just ahead of their vertical axis at the bottom of their revolution. The pressure on the wheels is maintained by three trunion bearings on the outside of each wheel. The wheels are driven by means of pinion gears and are fitted on the inside with brass screws and steel plates. A spadelike arrangement scrapes the press cake loose from the wheels at the bottom. The press liquor is squeezed out

through the screen on each wheel. It is calculated that this press has a capacity of from 4 to 12 tons per hour, depending on the type of material being pressed and the amount of pressure desired to remove the moisture.

It is possible to purchase cooker-press equipment built as a single unit. These



(Courtesy P and L Welding and Machine Works)

FIG. 22–6. Continuous de-watering press for removing the water from fish meal.

units are graded as to size by the amount of fish which can be handled per hour. Butler (1949) gives the following estimates as to cost and size.

"Although units of from 1- to 5-ton per hour capacity are available, the most common continuous steam-cooker screw-press type of equipment usually installed has a raw-material capacity of 10 tons per hour. Such an installation includes the grinders, conveyors, cooker, press, drier, the oil-settling tanks, sacking and meal-collecting equipment, all motors, valves, and similar equipment, but not piping and wiring. The cost f.o.b. manufacturer's plant for the 10-ton per hour plant is approximately $64,000 for the steam-tube meal drier design and $54,000 for the direct-heat drier design. A recently announced fish-scrap processing plant is designed to handle from 1 to 2 tons per hour by the wet reduction process. Equipment is similar to that just listed except that no drier is included. The price quoted is approximately $17,000. The press cake could be handled in either a small direct-heat or steam drier, as for the 10-ton size plant, or in a single dry-rendering type batch-drier described below. The latter drier unit, complete with the grinders, conveyors, collecting and sacking assembly, and motors, would cost approximately $22,000. If the fish scrap is wet-processed prior to the batch-drying by this method, the capacity of the combined equipment may be estimated at about 24 tons of raw fish scrap per 12-hour day."

Drying the Fish Meal. When the pressed material leaves the presses, it is conveyed to a grinder where it is broken up into small pieces. It then passes into one of several types of drying equipment where the moisture is reduced to 6 to 8 per cent.

Direct-Heat Drier. This type of drier is composed of a furnace in which the heat is generated. Hot gases are forced through a cylinder which is slightly declined from the furnace. The size of these cylinders varies from 4 to 6 feet in diameter and 40 to 50 feet in length. They are mounted on trunion rings and slowly rotated. Inside the cylinders are fixed fins or plates which carry the meal up toward the top and then spill it back through the hot gases passing through the

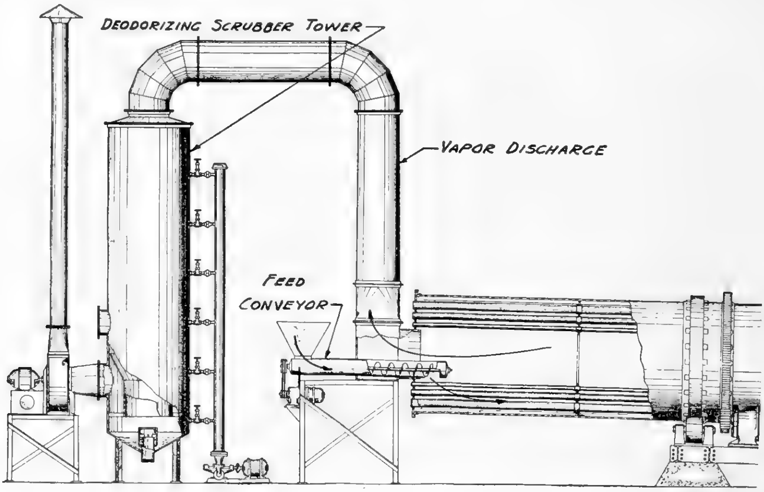


FIG. 22–7. Renneburg steam tube drier with

cylinder. The wet meal enters the cylinder near the furnace, and the rotation of cylinder and fins gradually work the meal towards the opposite or discharge end of the drier.

Considerable care is required in adjusting the heat of the gases in the drying cylinder since a high temperature may scorch the meal and considerably reduce the protein content. Since fish meal for animal feeding is purchased on protein value, most processors carefully regulate the heat used in drying.

In some driers a forced draft is employed. A blower pulls the hot gases through the drier, and the exhaust from the blower goes into a cyclone separator. Small particles of fish meal are separated from the gases in the cyclone, and the gases are returned to the furnace where any objectionable odors are destroyed by burning.

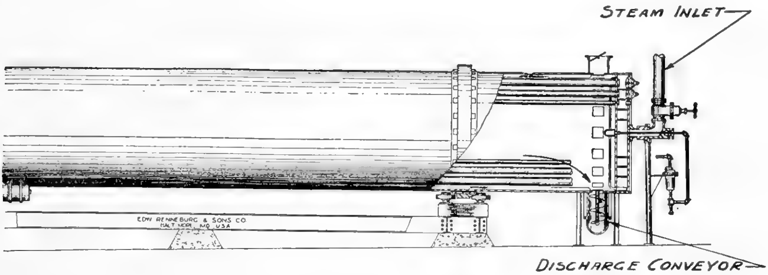
Steam-Tube Drier. The steam-tube drier resembles the direct-heat drier in outward appearance, but differs from it on the inside. Steam tubes are arranged in concentric circles with a header at each end. The steam inlet and outlet are centered in the axis of the drier and fitted with suitable stuffing boxes to retain the steam pressure.

As the drier cylinder rotates, the fins on the inside lift the fish meal, carry it toward the top, and drop it through the spaces between the steam tubes. The blower carries away the warm moist air and deposits the small particles of meal in a cyclone separator. The gases are taken care of in the same manner as described for the direct-heat drier.

Air-Lift Drier. There are two types of air-lift driers: vertical and horizontal. While both operate on the same principle, they are constructed differently. Both are highly efficient and are able to produce a dried product of a high grade since the temperature can be kept low, thus eliminating the likelihood of scorching. They also reduce the discharge of objectionable odors into the air.

One type is designed in the form of a vertical tower, the height and diameter of which is controlled by the quantity of the material to be handled. Heat is generated in a furnace or by a bank of steam coils, and introduced at the bottom. A high-velocity blower, situated at the top of the tower, pulls a sufficiently large volume of air upward and holds in suspension the particles of wet material fed in near the bottom. As the particles lose moisture, they become lighter and finally float out through the blower and are caught in a cyclone separator.

The horizontal-type drier is composed of an outside stationary cylinder and two



(*Courtesy Edw. Renneburg and Sons Co.*)

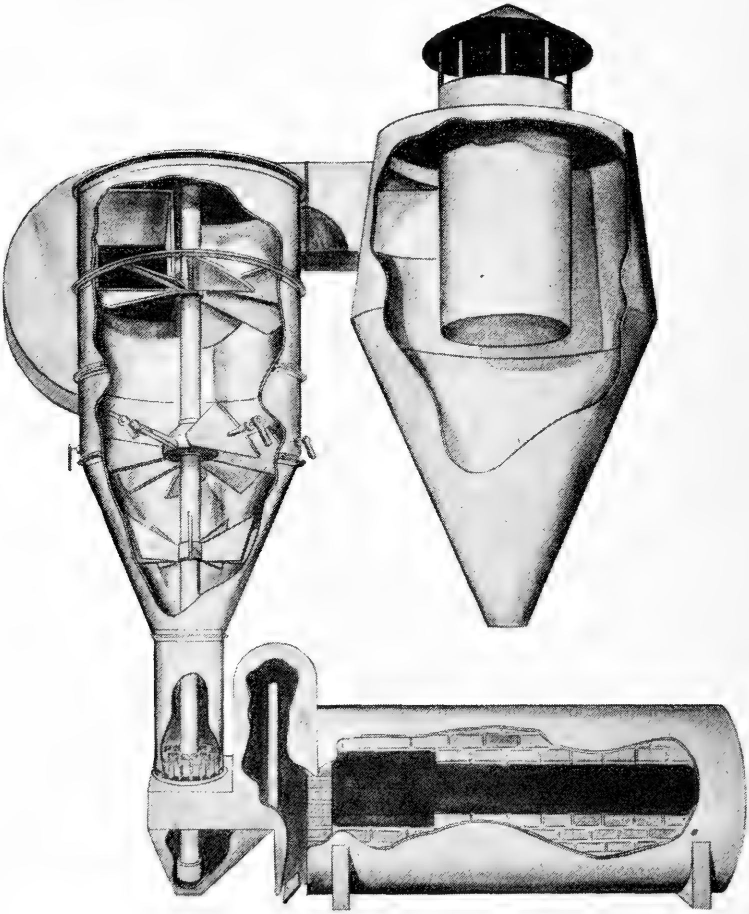
deodorizing tower for drying fishmeal.

inside rotating cylinders, one inside the other. These cylinders are arranged in the form of baffles. The material travels three times the length of the drier before being discharged in a cyclone-separating arrangement at the dry end. A furnace is the source of heat, and a blower pulls a high-velocity stream of air through the drier. The wet material is fed into the inner cylinder, and as it dries is carried through by the air current. The rotation of the cylinders prevents the wet material from sticking to the sides and forming a cake. It is claimed that this drier has the capacity to evaporate 6 to 8 thousand pounds of water per hour.

Vacuum Drier. The equipment for drying under a vacuum is almost identical with that described under the "dry-reduction process." The wet material is loaded into the drier, and the moisture evaporates under reduced pressure of approximately 29 inches of mercury. Heat is produced by the low-pressure steam in the jacket of the drier. The meal produced under these conditions is of a high quality because of the low temperature of the drying. The costs of meal production by this method are slightly higher than the others previously mentioned.

Handling Odors. As a general rule fish-meal plants are seriously troubled with odors. In many instances the plants have been declared a nuisance and have had legal difficulty until the odors were controlled. The gases from the drier, regardless of the type, may be recirculated and passed through the furnace, where the heat of the combustion destroys the odors. Another common method for

eliminating odors is by scrubbing. The gases from the drier are passed into a tower containing a number of water sprays. The fine spray absorbs objectionable odors and carries them into the sewer.



(*Courtesy P and L Welding and Machine Works*)

Fig. 22–8. A cut-away showing the internal construction of the air-lift drier.

Packaging the Fish Meal. When the dried meal is discharged from the drier, its temperature varies between 200 to 400° F (93 to 204° C). It contains from 6 to 10 per cent moisture and from 3 to 6 per cent oil, depending upon the efficiency of the plant. Many plant operators spread the meal over the floor to cool before weighing it into 100-pound bags. Sacking the hot meal frequently causes excessive heating due to continued oxidation of the oil contained in the meal. The greater the oil percentage the greater the heating of the sacked meal. Heating results in an inferior grade of meal, which consequently brings a lower price. Harrison (1939) found that placing the hot meal in double-wall paper bags, with

an asphalt binder between the walls, reduced the oxidation and deterioration. This method of handling makes it possible to sack the meal as it leaves the drier, saves the labor required to handle it on the floor, and improves its quality.

Calculation of Yields

There are several factors which influence the yield of dry fish meal and oil in the operation of a plant. In general 1 ton of fish will furnish 400 pounds of dry meal and 1,600 pounds of press liquor. The press liquor will contain approximately 280 pounds of oil, and 65 pounds of solid protein particles are carried through the press with the liquor.

If the fish are of poor quality, there will be a deviation from this generalization. Early in the season the fish are often fatter and the yield of oil will be greater. Poor quality fish are often the cause of more suspended particles of protein in stickwater, and if not recovered may cause higher production losses. Even the type of equipment and its manipulation influence the final profits of the plant. The percentage of protein in fish is quite constant regardless of the species, but the water and fat vary considerably. Since a fat fish contains less moisture than a lean one, the average proportion of meal recovered is constant, while the oil yield varies with different species.

Daniel and McCollum (1931) have reported the analysis of several samples of fish meals from different species of fish, dried by different methods (Table 104). In the same report they indicate that vacuum-dried fish meals have a higher nutritive value than flame-dried. They also report that vacuum-dried cod and menhaden meals have a similar feeding value. Most animal nutritionists agree that flame drying generally reduces the feeding value of fish meal. This defect can be overcome by lowering the temperature of the flame drier.

Table 104. Composition of Fish Meals Manufactured in Various Ways.

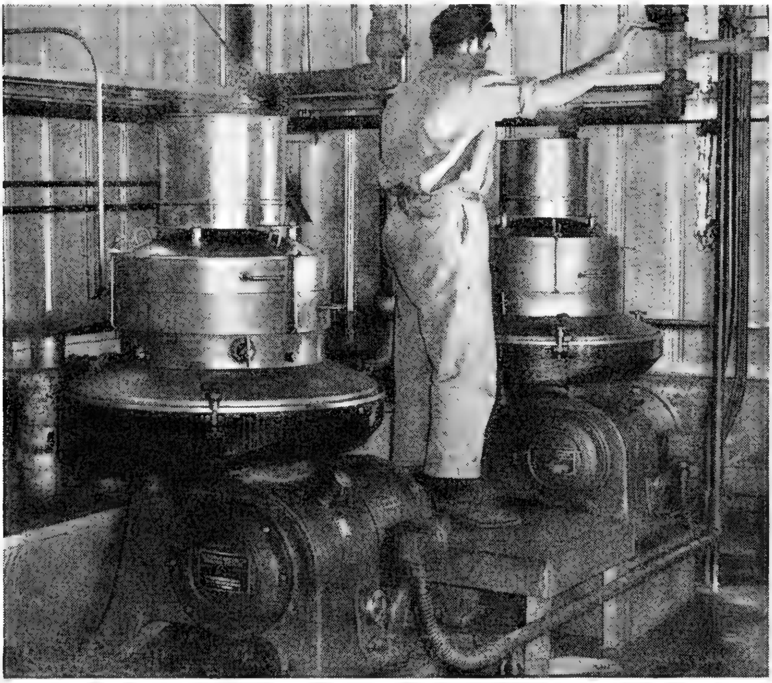
Method of Drying and Species	Moisture %	Protein %	Ash %	Oil %
Steam-dried menhaden	10.58	62.31	18.34	7.77
Flame-dried menhaden	9.25	61.25	20.56	7.14
Flame-dried whitefish	6.10	62.00	29.53	1.14
Vacuum-dried whitefish	12.52	67.88	19.20	1.90
California pilchard	5.94	61.88	20.89	3.54

Source: Daniel, E. P., and McCollum, E. V., "Studies of the Nutritive Value of Fish Meals," U. S. Fish and Wildlife Service, *Investigational Rept.*, 2 (1931).

Press Liquor and Oil

The liquid fraction which passes through the screen of the press and is caught in a drip pan or some other device contains water with some soluble portions of fish, oil, and suspended protein. These materials are separated by first being passed through a vibrating screen or some other type filter. This removes all of the suspended material, which is then put through a small "foots-press." The solids recovered in this device are added to the meal. The liquor is either placed in settling tanks for gravity separation of the oil or put through a centrifuge system for the separation of the oil and water fractions. In the most efficient plants centrifugal separators have largely replaced the settling tanks for the recovery of the oil.

Centrifuge System. There are two types of centrifuges used in the separation of press liquor into its component fractions. The first is a 3-phase machine designed to separate oil, water, and some suspended material. The solids and some water are discharged from one port, the oil containing a small amount of water as an emulsion from a second port, and the remainder of water from a third port. The



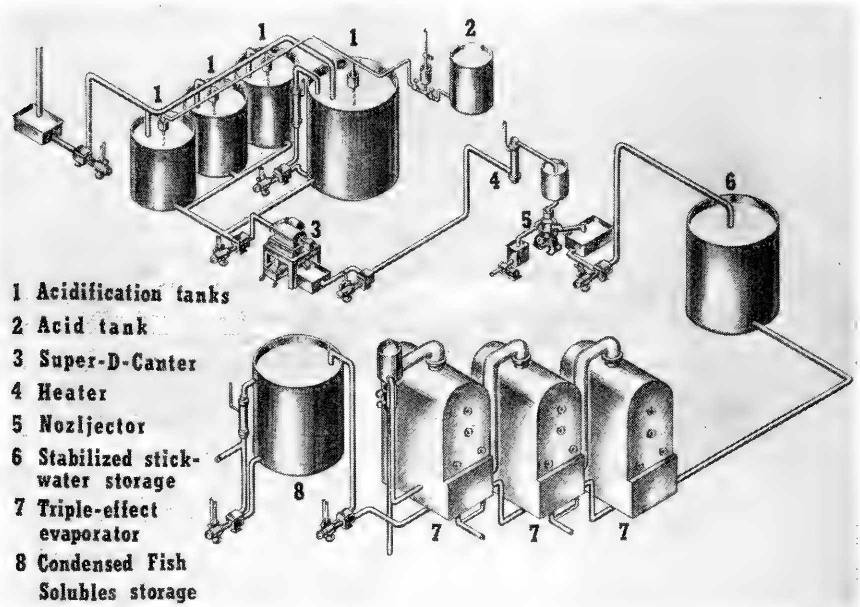
(Courtesy Sharples Corp.)

FIG. 22–9. Battery of Nozljectors for separating oil, water, and suspended protein material.

oil emulsion is passed through a second centrifuge, termed an oil purifier, for a complete separation of the oil and water. After passing through the second centrifuge the oil is ready for market. The water from the oil separation is returned to the receiving tank in which water from the first separation is stored. The solids are separated by the screen or filter system just referred to.

Condensation of Press Water. The water fraction from the above separations is known as "stickwater" or fish "solubles," and contains minerals, vitamins, amino acids, and many other valuable nutritional ingredients. When dumped into public waters this waste product becomes a nuisance. Because of its nature it putrifies easily and gives off revolting odors. Since it contains proteinaceous compounds, it is an excellent medium for bacterial growth, and thus may become a public health hazard. For many years fish meal manufacturers failed to recognize the potential value of this waste product when properly condensed and mixed with cattle and poultry feeds. After years of study and experimentation the present process was developed.

The "stickwater" from the meal and oil separation is collected in a receiving tank. The size of the plant controls the capacity of the tank. When the receiving tank is full, the "stickwater" is pumped into iron storage tanks for further treatment. During the filling of the storage tanks a predetermined quantity of sulfuric acid is added slowly until a pH of 4.5 is reached. Normally the "stickwater" has a



(Courtesy Sharples Corp.)

Fig. 22–10. Flow sheet for the Sharples-Lassen stickwater process.

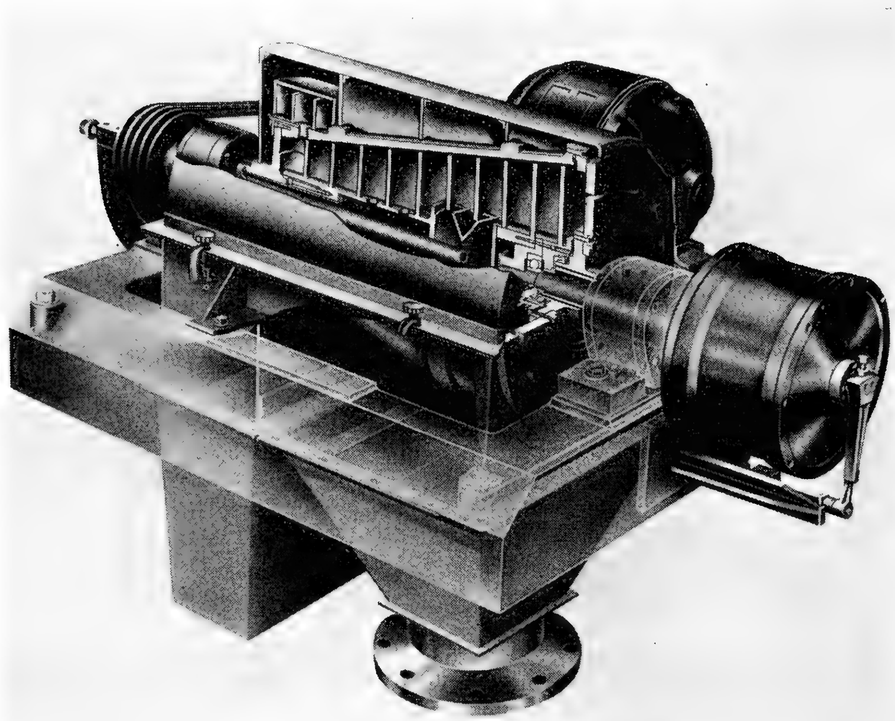
pH value of 6.0 to 7.0. The condition of the original fish and the length of time required for processing are reflected in the pH of the "stickwater."

The storage tanks are fitted with steam coils and the temperature is held at 150° F (66° C) for 30 minutes to complete the coagulation of some of the proteins and the precipitation of the enzymes. When this reaction is complete, the "stickwater" contains approximately 5 per cent protein in solution, which is recovered during concentration.

After the above manipulation the stickwater is passed through a clarifying centrifuge to remove all of the precipitated solid. During this centrifuging a small amount of oil, approximately 1.0 per cent, which has probably been entrapped mechanically by the suspended protein, is recovered. It has been estimated by some operators that the oil recovered at this point is of sufficient value to pay for the centrifuge during 1 year's operation. This, however, would depend upon a number of factors, and probably cannot be accepted by all operators, or for all species of fish. The oil recovered from the acidulated stickwater is usually a darker color than that recovered from the original press liquor; it is generally used for blending with other oils, or marketed as a lower grade. The stickwater from

the centrifuge enters a storage tank from which it is fed directly into the evaporators, where it is concentrated.

The suspended particles of fish flesh recovered by the centrifuge are higher in protein value, especially in riboflavin, than those discharged from the presses. In some plants these are added to the press-cake meal to enrich it; in others they



(*Courtesy Sharples Corp.*)

Fig. 22–11. Super-D-Canter removes fish meal from acidulated stickwater. Photo shows internal construction.

are dried separately and sold at a price about 1½ to 2 times more than that of the usual plant meal. The recovery of this material amounts to approximately 10 pounds per 1 ton of the fish processed in the general operation of the plant.

Concentration of Stickwater. The concentration of the stickwater is completed by means of vacuum evaporators, operated in sets of three or more units. The two principal designs for these evaporator units are the horizontal and vertical; their names derive from the position of the steam tubes which furnish the heat for concentrating the liquors. Both types are used in stickwater plants. Usually a decision as to the type to be installed in a particular plant depends upon a number of engineering factors. Available floor space is one of the most important of these.

Each of the evaporator units is divided into two entirely separate compartments: first, a series of tubes through which steam circulates to furnish heat for the evaporation of the excess water in the liquor; second, the compartment contain-

ing the liquor in a pan. The steam tubes passing through the pan are completely covered with liquor at all times during actual evaporation.

The pans in which evaporation takes place are enclosed and are operated under reduced pressure, maintained by vacuum pumps and vapor condensation. The first unit is heated by means of low-pressure steam passing through the tubes; usually this is exhaust steam from engines or pumps. Since the liquor to be concentrated in this unit is under reduced pressure of about 24 inches (600 mm) of mercury, it boils at a lower temperature. As the liquor reaches a predetermined concentration, it is drawn into the second evaporation unit. The vapors from the boiling liquor in the first unit are passed through the steam tubes of the second. The partially concentrated liquor in the second unit continues to boil under an increased vacuum of about 28 inches (700 mm) of mercury, thus further lowering the boiling temperature. In the third and last unit the evaporation is completed under reduced pressure of approximately 30 inches (750 mm) of mercury. The vapors from the second evaporation unit boil the liquor drawn over from the second unit into the third unit.

The valves controlling the flow of liquor from the supply tank into the first evaporator unit and between the other units can be adjusted so that the operation is continuous. A discharge of the finished concentrate of standard density is assured by this controlled system.

When the concentration of the liquor in the third unit reaches approximately 50 per cent solids, it is considered finished and passes into storage tanks for future shipment to feed mixers.

During evaporation the original liquor has been reduced in volume by approximately 90 per cent (i.e., approximately 90 pounds of water has been removed from each 100 originally contained in it). It contains sufficient acid to prevent either bacterial or proteolytic decomposition, even though stored over a considerable period of time at ordinary temperatures.

This condensed stickwater is valued by dry-feed mixers for inclusion in mixed animal foods. The moisture content is such that it is readily absorbed by such feed material as alfalfa meal, wheat middlings, etc. without materially affecting the total moisture content of the feed. The high animal protein growth factor contained in it promotes the rapid development of farm animals when it is used as an ingredient in the feeds.

Analysis of Condensed Fish Solubles. Sharples-Lassen (1949) have given the following analysis as being typical of condensed fish solubles prepared from pilchard on the basis of 50 per cent total solids:

	%
Protein (Minimum)	32.00
Fat (Minimum)	4.00
Fiber	0.00
Ash	9.00

Minerals

	%		%
Calcium (Ca)	0.87	Magnesium (Mg)	0.016
Phosphorus (P)	0.85	Sodium Oxide (Na_2O)	1.87
Iron (Fe)	0.025	Potassium Oxide (K_2O)	1.93

Amino Acids

	% of Protein		% of Protein
Arginine	4.34	Tryptophane	0.35
Histidine	5.79	Methionine	1.51
Lysine	4.87	Threonine	2.35
Leucine	4.67	Cystine	0.58
Isoleucine	2.73	Glycine	10.90
Valine	2.98	Glutamic Acid	8.44
Phenylalanine	2.33		

Vitamins

	Mg per lb
Riboflavin	8 to 9
Pantothenic Acid	18.00
Thiamin	1.80
Nicotinic Acid	150.00
Pyridoxin	5.00
Choline	1500 to 1800

Liquid Fish

Some fish waste is converted into a wet or semiliquid protein supplement for use in animal and poultry feed. The waste material used in the preparation of this liquid protein or "liquid fish" consists of the inedible remains after fillets are cut. The most generally used species of fish are those ordinarily known as non-fatty fish: cod, haddock, pollock, redfish, etc. The bodies of these species contain slightly more than 1 per cent oil, and are not valuable as a source of fish body oil. Some whole fish which have no value as food are often sold for reduction purposes.

This process is in the early stage of development; even though a firm may be preparing and marketing the liquid fish, many problems remain to be solved. At present it is impossible to obtain technical details as to manipulation. The waste material is chopped into small pieces; these are placed in some form of digestion apparatus where the fish flesh is hydrolyzed to produce the constituent amino acids which compose the complete protein.

One method for accomplishing hydrolysis or partial digestion is by adding acid and heating the mass at a temperature of approximately 150° F (66° C). The naturally occurring enzymes of the fish flesh and viscera are activated by the acid and increased temperature and result in a partially digested liquid protein. The time varies according to the particular material under treatment. The acid mixture should be agitated during the heating period to insure uniform reaction throughout the mass.

When hydrolysis is completed, it is necessary to condense the material to about 50 per cent solids. This is done by evaporating some of the excess water content either at atmospheric pressure or under reduced pressure. A lower temperature is required for reduced pressure consequently there is no danger of scorching the finished product. After this reaction is completed and the water removed, a slight quantity of acid remains and acts as a preservative. The "liquid fish" is shipped in tank cars to the feed mixers, where it is included in a dry mixed feed.

One of the problems in connection with this process is the digestion of the bones. Little difficulty is experienced with small bones, but the larger ones are not sufficiently digested. It is necessary to remove them by some form of straining, followed by either digesting with stronger acid and enzyme action or grinding. Bones are highly desirable in feed as they furnish the needed calcium and phosphorus for a properly balanced diet.

Fish Meal

In general fish meal is now classified as an animal feed rather than as a fertilizer. This change has been a result of improved methods of manufacture as well as recognition of the concentrated high quality protein value. It is usually mixed with other feed materials, such as alfalfa meal, bran, or other vegetable materials, and an analysis of the food value is placed on the container. Fish meal is sold on the basis of its protein content, and rated according to the per cent of protein contained in the feed or fish meal. Therefore, producers have all tried to prepare a high protein value meal by improving their methods of manufacture.

General Characteristics of Fish Oils

Fish oils are liquid fats and consist chiefly of various proportions of the glycerides of saturated and unsaturated fatty acids. Vegetable and animal oils may be divided into three general classes (viz., nondrying, semidrying, and drying), according to their ability to absorb oxygen from the air and thus be converted into solid insoluble compounds. Fish oils belong to the two latter classes. Menhaden, sardine, salmon, herring, bonito, albacore, mackerel, stickleback, akajei, anchovy, and whiting oils are classed as drying, and may be used for the manufacture of paints, varnishes, and other materials. Whereas dab, sprat, hoi, and carp oils have relatively low iodine values and must be classed as semidrying oils, they cannot be used in paints and varnishes since upon drying they do not absorb sufficient oxygen from the air to form hard nontacky films.

Fish oils are obtained from all parts of fish, whereas fish-liver oils are prepared from the livers only. The bodies of liver-oil yielding fish, such as cod, are, as a rule, very lean and yield very little oil; whereas the livers of fatty fish usually contain little oil. Fish oils differ in chemical composition from liver oils, chiefly in that the latter contain relatively high amounts of an unsaponifiable substance called cholesterol.

The exact nature of the fatty acids in fish oils is still imperfectly known. Most of the oils deposit small amounts of stearin upon standing in the cold for long periods. Fish-oil stearin usually consists of a mixture of the glycerides of stearic and palmitic acids. It has been found that the fatty acids obtained upon the hydrolysis of menhaden oil contained 22.7 per cent palmitic acid and 1.8 per cent stearic acid, the glycerides of which are solid fats. The fish oils listed above as drying oils contain relatively high proportions of the glycerides of highly unsaturated fatty acids; whereas semidrying oils contain lesser amounts of these glycerides. All marine animal oils contain erucic acid

$$\begin{array}{l} C_8H_{17}-C-H \\ \qquad\quad \| \\ \quad H-C-\ (CH_2)_{11}-COOH \text{ or } (C_{22}H_{42}O_2) \end{array}$$

and an unsaturated fatty acid of the formula $C_{20}H_{38}O_2$. A large number of fish, liver, and blubber oils contain from 6 to 9 per cent of the glycerides of clupanodonic acid $C_{18}H_{28}O_2$. The free fatty acid is a pale yellow liquid having a fishy smell. Many observers have attributed the characteristic odor of fish oils to the presence of this acid. It has been shown that upon slight hydrogenation of the oils the fishy odor is practically destroyed. Since this is one of the most highly unsaturated acids in fish oil, it is one of the first to combine with hydrogen upon such treatment.

Iodine Number of Fish Oils. The iodine number is an empirical value which is useful in classifying the saturation of the oils. Those having a low "iodine number" are highly saturated and are suitable for inclusion in edible products. Oils having a high iodine number are suitable for hydrogenation and inclusion in products where a drying oil is desired, such as paint, varnish, printer's inks, soap, etc. Therefore, the purchaser is interested in the iodine value of the oil for it gives him an idea of the use to which the oil can be put and assists him in the determination of its market value. The iodine number is useful only in the determination of the degree of saturation of an oil and has no value in differentiation between animal and vegetable oils.

For purposes of differentiation of fish oils and vegetable oils the bromide test is suggested. Owing to the presence of clupanodonic acid in fish, liver, and blubber oils this test is suggested for the purpose of distinguishing between the drying and semidrying oils.

Dissolve 1 to 2 g of oil in 40 cc of ether to which a few cc of glacial acetic acid have been added. Cool the solution in a corked flask to 41° F (5° C) and add bromine drop by drop from a finely drawn-out pipette until the brown coloration remains permanent. (If the temperature were allowed to rise, evolution of hydrobromic acid would become noticeable. In that case the experiment must be rejected.) After standing for 3 hours at a temperature of 122° F (50° C) the liquid is filtered through a plaited filter, and the precipitate washed 4 times in succession, using each time 10 cc of chilled ether. The residue is finally dried in water over constant weight.

Clupanodonic acid forms octobromostearic acid ($C_{18}H_{38}O_2Br_8$) upon bromination. This substance contains 69.87 per cent bromine, blackens at 392° F (200° C), and decomposes upon further heating. Decomposing before melting may be used as a qualitative test to distinguish between this bromide and linolenic hexabromide, as the latter melts at 356 to 357.8° F (180–181° C). Linolenic hexabromide is the ether insoluble bromide obtained upon the bromination of fatty acids from linseed oil. Thus, deodorized fish oil may be distinguished from linseed oil and other vegetable drying oils. The ether insoluble bromo derivatives consist of octobromide, hexabromide, or a mixture of both. Since clupanodonic octobromide contains 69.87 per cent and hexabromides about 63.32 per cent bromine, the amounts of the respective acids can be calculated from the following two equations:

$$x + y = 100$$

$$\frac{69.87x}{100} + \frac{63.32y}{100} = B$$

Thus, x is the percentage of octobromide, y the percentage of hexabromide, and B the percentage of bromine in the ether insoluble bromides.

Since fish, fish-liver, seal, whale, and sperm oils are the only oils known to contain large amounts of the glycerides of clupanodonic or other highly unsaturated acids capable of forming octobromides, this test may be used to distinguish between marine animal oils and vegetable drying oils.

Fish oils when treated with nitrous acid, as in the elaidin test, yield either a liquid product or a pasty or buttery mass separating from the fluid portion. Non-drying oils yield solid hard masses when treated with nitrous acid.

Old marine animal oils and those bleached by sunlight yield dark brown soaps upon hydrolysis with alkalies, whereas the freshly prepared oils give slightly colored soaps.

Menhaden Oil. The production of menhaden oil as shown in Table 103 far exceeds that of any other fish body oil.

Composition. The maximum and minimum constants for menhaden oil that have been published are given below:

Specific gravity at 59° F (15° C)	0.9284–0.9311
Solidifying point ° F	24.8 (− 4° C)
Saponification value (mg. KOH)	188.7–193.0
Reichert value (cc $\frac{N}{10}$ KOH)	1.1
Iodine value (per cent)	147.9–192.9
Maumene test ° F	253.4–262.4° (123–128° C)
Specific temperature reaction	306
Butyro refractometer 104° F (40° C)	71.3–72.0°
Unsaponifiable matter (per cent)	0.61–1.60

The high saponification value, the small amount of unsaponifiable matter, and the high proportion of glycerol yielded upon saponification show that menhaden oil consists almost entirely of glycerides.

The composition of the fatty acids of menhaden oil has been determined by observing the lowering of the melting point by the addition of pure fatty acids. This indicates the following composition:

	%
Palmitic acid	22.7
Myristic acid	9.2
Stearic acid	1.8
Unsaturated acids with 16 carbon atoms	None
" " " 18 " "	24.9
" " " 20 " "	22.2
" " " 22 " "	20.2

The unsaponifiable matter consists chiefly of cholesterol, which causes the slight optical activity of this oil.

Use. Much menhaden oil is hydrogenated and used for the manufacture of soaps. When properly hydrogenated a solid, odorless, almost colorless fat is produced. This hardened oil is extensively used in the manufacture of laundry soap

and the cheaper grades of toilet soap. Some is also used for the preparation of certain lard and butter substitutes. In Europe menhaden and other fish oils and whale oils are hydrogenated and used in the manufacture of candles, soap, leather dressing, table and cooking fats, and other edible and nonedible products. The iodine numbers of such hardened oils vary from about 8 to 70, depending upon the quality; the lower the iodine value the higher the quality.

Some menhaden oil is used in the manufacture of artificial leather and as a quenching medium for tempering steel products. Another use is in soaps contained in insecticidal sprays. It is used in printer's inks and textiles and as a core oil in the foundry. These are not highly important uses as they require only small amounts of the total production.

Menhaden oil is also used in the manufacture of paints, varnishes, and stains. For this purpose winter oil must be used as stearic acid forms insoluble compounds with drying substances. These insoluble compounds slowly precipitate out from the varnish or paint on standing and cause flecks in the film. Menhaden oil is especially valuable in the preparation of certain heat-resisting paints. For roof and barn paints and coatings for structural steel menhaden oil is excellent because the dried film is not as brittle as that formed by linseed oil, and it is somewhat less affected by sudden changes of temperature. Heat-treated oil containing driers must be used as raw-oil film is somewhat tacky even when completely dry. In white paints rather large amounts of driers are required to dry the oil to a permanently hard film, and thus prevent the darkening caused by dust adhering to tacky film.

Formerly, its principal use was in the currying trade and in the manufacture of degras and sod oil; large quantities are still employed by leather manufacturers. Some are used in the manufacture of linoleum and for making rubber substitutes and water-proofing compositions.

Small amounts of menhaden oil are used in animal and poultry feeds when it is found to contain sufficiently high vitamin A and D. This use is of minor importance.

Miscellaneous Oils. Three species of herring are used in the manufacture of oils. The herring (*Clupea harengus*), which are taken off the coast of Maine, are caught primarily for canning. Only those which are too large to can and those in poor condition go to the reduction plants.

Alaska herring (*Clupea pallasii*), found in Alaskan waters, are used in considerable quantities for the production of oil and meal. This species is used to some extent for salting and smoking.

Alewife or river herring (*Pomolobus pseudoharengus* and *Pomolobus aestivalis*) are found in the Chesapeake Bay area. The reduction of these species is incidental to the curing industry, and the production of oil and meal is small. Herring oil is used in the feeding industry and in the production of soap. In Norway herring oil is refined and used as a substitute for olive oil in the sardine-canning industry.

Anchovies furnish a source of oil on the Pacific Coast. Oil from this source is not of great importance, and it is usually produced along with the pilchard.

Salmon oil is produced from the reduction of cannery waste, and is used primarily in animal feeding. It is refined to some extent before being marketed.

Tuna oil is produced as a by-product of the canning industry. When the tuna are precooked prior to canning, the oil is recovered and used as a feeding oil.

All of the waste products, including heads, viscera, and the dark portions of the fish, are used in the production of oil and meal.

There are a number of other species which enter into the production of meal and oil, but the volume is small. Some of these species are: redfish trimmings, halibut heads, carp, and burbot.

REFERENCES

Anderson, A. W., Harrison, R. W., and Pottinger, S. R., "Studies on Drying Cod and Haddock Waste," U. S. Fish and Wildlife Service, *Investigational Rept.*, 32 (1935).

Anon., "Utilization of Fish Cannery Wastes," *Food Mfg.*, **16**, 49 (1941).

Anon., "Fish Meal and Oil," *Fishing Gazette*, **66**, No. 6, 64–66 (1949).

Anon., "Utilization of Alaska Salmon Cannery Waste," Parts I and II, U. S. Dept. of Commerce, Office of Technical Services (1948).

Anon., "The By-products Situation Existing in Europe Today," *Fishing Gazette*, **66**, No. 5, 63 (1949).

Anon., "The Practical Importance of Quality in Condensed Fish Solubles," *Pacific Fisherman*, **47**, No. 8, 36 (1949).

Anon., "There's Good Hard Cash in Stickwater," *Food Industries*, **22**, 242 (1950).

Baldwin, W. H., and Parks, L. E., "The Body Oil from Menhaden (*Brevoortia tyrannus*): A. Low Temperature Crystallization of Glycerides. B. Some of the 18 and 20 Carbon Atom Acids," *Oil and Soap*, **20**, No. 6, 101–104 (1943).

Berry, E. P., Carrick, C. W., Roberts, R. E., and Hauge, S. M., "Condensed Fish-Press Water and Fish-Liver Meal in Chick Rations," *Poultry Sci.*, **24**, No. 3, 3 (1945).

Brocklesby, H. N., "Chemistry and Technology of Marine Animal Oils," Fisheries Research Board Canada, *Bull.*, **59** (1941).

Brocklesby, H. N., "The Chemistry of Marine Mammal, Fish, and Fish-Liver Oils as Related to Their Utilization in World Commerce," *Proc. of the Sixth Pac. Sci. Cong.*, **3**, 291, Berkeley, Univ. of Calif. Press (1939).

Butler, C., "Fish-Reduction Processes," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **129** (1949).

Cameron, T., "New Hydro-Vac Lift Speeds Fish Direct from Boat to Cannery," *Food Industries*, **21**, No. 11, 92 (1949).

Carlson, C. B., and Foster, K. P., "Experimental Purse Seine Fishing for Menhaden with the *Jeff Davis*," U. S. Fish and Wildlife Service, *Supplement, Fishery Market News*, **7**, 5a (1945).

Daniel, E. P., and McCollum, E. V., "Studies of the Nutritive Value of Fish Meals," U. S. Fish and Wildlife Service, *Investigational Rept.*, **2** (1931).

Fiedler, R. H., "The Factory Ship," *Proc. of Sixth Pac. Sci. Cong.*, **3**, 273, Berkeley, Univ. of Calif. Press (1939).

Harrison, R. W., "The Menhaden Industry," U. S. Fish and Wildlife Service, *Investigational Rept.*, **1** (1931).

Harrison, R. W., "Market for Marine Animal Oils in the United States," U. S. Fish and Wildlife Service, *Investigational Rept.*, **7** (1931).

Harrison, R. W., "Some Aspects of Fish Meal Manufacture and Distribution," *Proc. of Sixth Pacific Sci. Cong.*, **3**, 309, Berkeley, Univ. of Calif. Press (1939).

Harrison, R. W., and Pottinger, S. R., "Commercial Production of Menhaden Fish Oil for Animal Feeding," U. S. Fish and Wildlife Service, *Investigational Rept.*, **4** (1931).

Hatton, S. R., and Smalley, G. R., "Reduction Processes for Sardines in California," Calif. Div. of Fish and Game, *Fish Bull.*, **24**, 391–414 (1938).

Ingvaldsen, T., "Fish Meals. Part I. The Effect of High Temperature Employed for Drying on the Nitrogen Partition," *Can. Chem. and Met.*, **13**, 97–99 (1929).

Kraybill, H. F., and Nilson, H. W., "Chemical Studies of Lipoid Extracts from Men-

haden Fish Meal," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **9**, 9 (1947).

Lanham, W. B., Jr., and Nilson, H. W., "Some Studies on the Feeding Value of Fish Meals," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **9**, 8 (1947).

Lassen, S., and Bacon, E. K., "The Use of Condensed Fish Solubles in Poultry Nutrition," *Poultry Sci.*, **25**, 486–491 (1946).

Lassen, S., Bacon, E. K., and Dunn, H. J., "The Digestibility of Polymerized Oils," *Arch. Biochem.*, **23**, No. 1, 1–7 (1949).

Lassen, S., Bacon, E. K., and Dunn, H. J., "The Relationship of Nutritive Value of Condensed Fish Solubles to Quality of Raw Material," *Poultry Sci.*, **28**, 134–140 (1949).

Lovern, J. A., "By-products of the Fishing Industry," *Chem. and Ind.*, **56**, 75 (1937).

Lovern, J. A., "The Fishing Industries of North America. Part IV.—Fish Meal and Oil," *Food Mfg.*, **23**, 323–327 (1948).

Pottinger, S. R., and Baldwin, W. H., "The Content of Certain Amino Acids in Seafood," *Proc. of the Sixth Pac. Sci. Cong.*, **3**, 453, Berkeley, Univ. of Calif. Press (1939).

Sharples-Lassen Stickwater Process, *The Sharples Corp. Bull.*, **1245**, Philadelphia (1949).

Tarr, H. L. A., "Possibilities in Developing Fisheries By-products," *Food Technology*, **2**, 268–277 (1948).

Tarr, H. L. A., and Deas, C. P., "The Utilization of Fish Wastes. Bacteriological Peptones from Fish Wastes," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **75**, 43–45 (1948).

Tressler, D. K., "Opportunities for Research in the Menhaden Industry," *Fishing Gazette*, **41**, 10 (1924).

Tressler, D. K., "Menhaden Oil," *Fishing Gazette*, **41**, 18 (1924).

Walford, L. A., "The Pacific Sardine Fishery," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **129** (1947).

CHAPTER 23

Fish-Liver Oils

Introduction

The belief in the health-giving quality of fish-liver oils has been recognized for several hundred years. In fact, it is impossible to determine the exact date of the first use of these oils for this purpose. In the Middle Ages it is reported that fish livers were suggested as a treatment for rickets. As early as 1657 it was believed that "night blindness" was the result of a dietary deficiency which could be relieved by taking certain fish-liver oils. The discovery that they contain vitamins A and D has given a scientific basis for the early belief. This discovery also led to the idea that many kinds of fish livers might also be a source of these necessary dietary factors. Investigations of fish-liver oils have been continuously carried out during the past quarter of a century, with the result that vitamin oils and concentrates are now prepared from a large variety of fish livers.

In recent years it was found that vitamin D can be prepared by exposing certain substances—ergosterol and 7-dehydrocholesterol—to ultraviolet radiation. This has resulted in the elimination of fish-liver oils for their vitamin D content; but since they are the best source of naturally occurring vitamin A, in high concentrations, they are now much more sought after than previously. Not only have liver oils of a great number of known species of fish been assayed for vitamin A, but a large variety of sharks have been included in this search. Recently assays have been made of the liver oils of seals, both hair- and fur-bearing species.

Though vitamins A and D are both contained in most fish-liver oils, the market prices are based entirely upon the vitamin A content as expressed in U.S.P. units. In discussing the fish-liver oils here vitamin A will be given the major consideration for the above reason. To simplify the discussion the classification devised by Butler (1948) will be used. The fish livers are divided into three classes: (1) high oil content—low vitamin A potency; (2) low oil content—high vitamin A potency; (3) high oil content—high vitamin A potency.

Examples of the first of these classes are the cod, grayfish, and haddock, which have livers containing from 60 to 75 per cent oil by weight, and vitamin A potency ranging from 500 to 20,000 U.S.P. units per g. The second class is composed of tuna, halibut, sablefish, and others which have livers containing from 4 to 28 per cent oil by weight and vitamin A potency ranging from 25,000 to 600,000 U.S.P. units. All those livers which cannot be included in either of the first two groups are placed in a third group which is again broken down into two classes: those having an oil content of 40 to 75 per cent by weight and a vitamin A potency of 20,000 to 200,000 U.S.P. units, and those having from 25 to 75 per cent oil and 0 to 300,000 U.S.P. units of vitamin A per g.

The liver oil is contained in the protein of the livers and in some instances is

TABLE 105. VITAMIN A CONTENT OF OILS FROM FISHERY SOURCES HAVING COMMERCIAL IMPORTANCE IN THE UNITED STATES AND ALASKA.[1]

Common name	Scientific name	Area in which fish are caught	Source of oil	Per cent of round weight [2]	Oil content, per cent	Vitamin A content in U. S. Pharmacopoeia units per g of oil: Range	Vitamin A content in U. S. Pharmacopoeia units per g of oil: Average
Soupfin shark	Galeorhinus zyopterus	Pacific (male)	liver	10	55–68	45,000– 200,000	120,000
Soupfin shark	Galeorhinus zyopterus	Pacific (female)	liver	10	65–72	15,000– 40,000	32,000
Grayfish (dogfish)	Squalus suckleyi	Pacific-Alaska	liver	10	67–72	2,000– 20,000	5,000
Grayfish (dogfish)	Squalus suckleyi	Pacific-Hecate Strait	liver	10	65–70	7,000– 15,000	10,000
Grayfish (dogfish)	Squalus suckleyi	Pacific-Wash.-Ore.	liver	10	50–70	8,000– 25,000	14,000
Grayfish (dogfish)	Squalus suckleyi	Pacific-N. Calif.	liver	10	62–68	12,000– 20,000	15,000
Halibut	Hippoglossus hippoglossus	Pacific-Area 3 [3]	liver	1.5–3	8–21	40,000– 160,000	87,000
Halibut	Hippoglossus hippoglossus	Pacific-Area 2 [4]	liver	1 –1.75	17–27	20,000– 65,000	40,000
Halibut	Hippoglossus hippoglossus	Pacific	viscera [5]	2.5–5	2–5	70,000– 700,000	200,000
Sablefish	Anoplopoma fimbria	Pacific	liver	2 –2.5	10–26	50,000– 190,000	90,000
Sablefish	Anoplopoma fimbria	Pacific	viscera	3 –4	5–12	90,000– 250,000	125,000
Lingcod	Ophiodon elongatus	Pacific	liver	1 –1.5	8–20	40,000– 550,000	175,000
Lingcod	Ophiodon elongatus	Pacific	viscera	1.8–3	4–15	10,000– 175,000	40,000
Sleeper shark	Somniosus microcephalus	Pacific	liver	10 –15	40–55	5,000– 15,000	7,000
Mud shark	Hexanchus griseus	Pacific	liver	10 –15	60–65	5,000– 7,000	5,500
Great blue shark	Priomace glauca	Pacific	liver	[6]	30–45	7,000– 27,000	20.000
Hammerhead shark	Sphyrna zygaena	Pacific-Atlantic	liver	[6]	30–40	30,000– 120,000	50,000
Hammerhead shark	Sphyrna diplana	Pacific	liver	[6]	55–75	20,000– 150,000	60,000
Hammerhead shark	Sphyrna diplana	Atlantic	liver	[6]	[6]	5,000– 140,000	40,000
Hammerhead shark	Sphyrna tudes	Florida	liver	[6]	[6]	10,000– 125,000	50,000
Little black tip	Isogomphodon maculipinnis	Florida	liver	[6]	40–60	5,000– 25,000	5,000
Tiger shark	Galeocerdo arcticus	Florida	liver	[6]	45–60	2,000– 5,000	3,000
Sand-bar shark	Carcharinus milberti	Florida	liver	[6]	[6]	3,000– 15,000	8,000
Nurse shark	Giglymostoma cirratum	Florida	liver	[6]	[6]	1,000– 10,000	3,000
Dusky shark	Carcharinus obscurus	Florida	liver	[6]	[6]	5,000– 60,000	25,000
Leopard shark	Triakis semifasciatum	Pacific	liver	[6]	40–50	1,000– 5,000	3,000
Bay shark	Carcharias lamiella	Pacific	liver	[6]	60–75	2,000– 20,000	10,000
Thresher shark	Alopias vulpas	Pacific	liver	[6]	45–55	1,000– 5,000	3,000
Mexican shark	Eulamia lamiella	Pacific	liver	[6]	40–50	20,000– 80,000	40,000
Gray smooth hound	Mustelatus californicus	Pacific	liver	[6]	50–60	10,000– 25,000	20,000
Cazon shark	Unknown	Argentina-Brazil	liver	7 –10	30–45	10,000– 200,000	50,000
Albacore tuna	Germo alalunga	Pacific	liver	1.5–2	7–20	10,000– 60,000	25,000
Bluefin tuna	Thunnus thynnus	Pacific	liver	[6]	4–6	25,000– 100,000	75,000
Yellowfin tuna	Neothunnus macropterus	Pacific	liver	[6]	3–5	35,000– 90,000	50,000
Skipjack tuna	Euthynnus pelayms	Pacific	liver	[6]	4–6	30,000– 60,000	40,000
Bonito	Sarda chiliensis	Pacific	liver	[6]	4–12	15,000– 60,000	35,000
Swordfish	Xyphias gladius	Pacific-Atlantic	liver	1.4–2.6	8–35	20,000– 400,000	250,000
Swordfish	Xyphias gladius	Pacific-Atlantic	viscera	3 –6	6–12	2,000– 30,000	10,000
Black sea bass	Stereolepis gigas	Pacific	liver	[6]	13–20	100,000–1,000,000	300,000

Totuava	Cynoscion nobilis	Pacific	liver	[6]	15–25	40,000– 400,000	[6]
Cod	Gadus morhua	Atlantic	liver	3 –5	20–60	1,000– 6,000	2,000
Rosefish	Sebastes marinus	Atlantic	waste [7]	[6]	2–4	3,000– 5,000	[6]
Halibut	Hippoglossus hippoglossus	Atlantic	liver	1.5–2.5	15–25	40,000	[6]
Rockfish	Sebastodes	Pacific	liver	1 –1.5	5–25	14,000– 300,000	[6]
Rockfish	Sebastodes	Pacific	viscera	1.5–2.5	2–15	15,000– 125,000	[6]
Petrale sole	Eopsetta jordani	Pacific	liver	1 –1.5	6–25	4,000– 175,000	[6]
Herring	Clupea pallasii	Pacific	body	[6]	5–25	50– 300	90
Pilchard	Sardina caerulea	Pacific	body	[6]	5–25	50– 800	100
Menhaden	Brevoortia tyrannus	Atlantic	body	[6]	5–20	500	[6]

[1] These data compiled from reports of research at the laboratories of the Fish and Wildlife Service and of the Fisheries Research Board of Canada, and from articles published by representatives of commercial processors of fish livers and viscera. For the most part the data are based on large lots of material or on samples taken over the normal season for the species. Vitamin D data for some of these species are included in Table 3.

[2] Per cent of round weight means the proportion of liver weight to the weight of the entire fish (undressed) expressed as per cent.

[3] Area 3 is defined by the International Halibut Commission regulations as follows: "Area 3 shall include all the convention waters off the coast of Alaska that are between Area 2 and a straight line running south from the southwestern extremity of Cape Sagak on Umnak Island, at a point approximately latitude 52° 49′ 30″ N., longitude 169° 07′ 00″ W., according to Chart 8802, published January, 1942, by the United States Coast and Geodetic Survey, and that are south of the Alaska Peninsula and of the Aleutian Islands and shall also include the intervening straits or passes of the Aleutian Islands."

[4] Area 2 includes: "all convention waters off the coasts of the United States of America and of Alaska and of the Dominion of Canada between Area 1B and a line running through the most westerly point of Glacier Bay, Alaska to Cape Spencer Light, as shown on Chart 8304, published in June, 1940, by the United States Coast and Geodetic Survey, which light is approximately latitude 58° 11′ 57″ N., longitude 136° 38′ 18″ W., thence south one-quarter east and is exclusive of the areas closed to all halibut fishing in Section 9 of these regulations."

[5] Viscera, unless otherwise designated, means the contents of the body cavity, minus liver, stomach, and gonads.

[6] The source from which information listed here was obtained did not supply data under this heading.

[7] Waste is the entire body of the rosefish, minus fillet or edible portion; it includes head, backbone, skin, and viscera.

Source: U. S. Fish and Wildlife Service.

TABLE 106. VITAMIN A CONTENT OF OILS FROM FISHERY SOURCES HAVING LITTLE OR NO PRESENT COMMERCIAL IMPORTANCE IN THE U. S. AND ALASKA.[1]

Common name	Scientific name	Area in which fish are caught	Source of oil	Per cent of round weight [2]	Oil content, per cent	Vitamin A content in U. S. Pharmacopoeia units per g of oil
Basking shark	Cetorhinus maximus	Pacific	liver	[3]	60–70	300
Spotted cow shark	Notorynchus maculatus	Pacific	liver	6	29	1,400
Cod	Gadus macrocephalus	Pacific	liver	1.5–4	25–45	5,000– 17,000
Cod	Gadus macrocephalus	Pacific	viscera [4]	3.2–3.6	1.4–2.6	36,000–112,000
Cabrilla	Epinephelus analogus	Pacific	liver	[3]	13	164,000
Cormuda	Unknown	Pacific	liver	[3]	50	30,000
Pejerala	Unknown	Pacific	liver	[3]	27	98,000
Yellowtail	Seriola dorsalis	Pacific	liver	[3]	5–7	20,000– 40,000
Arrow-tooth halibut	Atheresthes stomias	Pacific	liver	[3]	10–15	10,000– 80,000
English sole	Parophrys vetulus	Pacific	liver	1–1.5	5–10	5,000
Starry flounder	Platichthys stellatus	Pacific	liver	1.5–2	10–15	1,000– 25,000
King salmon	Oncorhynchus tschawytscha	Pacific	liver	[3]	4–8	10,000– 40,000
King salmon	Oncorhynchus tschawytscha	Pacific	offal [5]	30	10–15	1,500– 2,000
Sockeye salmon	Oncorhynchus nerka	Pacific	liver	1.5–2	5–8	10,000– 50,000
Sockeye salmon	Oncorhynchus nerka	Pacific	offal	33	10–20	500– 5,000
Silver salmon	Oncorhynchus kisutch	Pacific	liver	1.5–2.5	4–6	10,000– 30,000
Silver salmon	Oncorhynchus kisutch	Pacific	offal	33	10–15	500– 3,000
Pink salmon	Oncorhynchus gorbuscha	Pacific	liver	[3]	4–6	1,000– 40,000
Pink salmon	Oncorhynchus gorbuscha	Pacific	offal	35	10–12	500– 3,000
Chum salmon	Oncorhynchus keta	Pacific	liver	1.5–2.5	2–6	5,000– 15,000
Chum salmon	Oncorhynchus keta	Pacific	offal	33	5–10	none
Steelhead	Salmo gairdneri	Pacific	liver	[3]	10–20	10,000– 20,000
Skate	Raja binoculata	Pacific	liver	[3]	30–60	500– 3,000
Starry skate	Raja stellulata	Pacific	liver	[3]	10–30	4,000– 30,000
Ratfish	Hydrolagus colliei	Pacific	liver	[3]	70–85	100– 1,000
Finback whale	Balaenoptera velefera	Pacific	liver	[3]	0.8	40,000
Sperm whale	Physeter macrocephalus	Pacific	liver	[3]	1.0	440,000
Beluga whale	Delphinapterus leucas	Pacific	liver	[3]	0.3	10,000
Bonito	Isurus glaucus	Florida	liver	[3]	40–50	500– 1,500
Mackerel shark	Carcharinus platyodon	Florida	liver	[3]	[3]	2,000– 4,500
Black-nose shark	Carcharinus scronotus	Florida	liver	[3]	[3]	1,200
No-name shark	Carcharinus falciformis	Florida	liver	[3]	[3]	6,600
Silky shark	Carcharinus floridanus	Florida	liver	[3]	[3]	2,000– 5,000
Bonnet-head	Sphyrna tiburo	Florida	liver	[3]	[3]	900
Great white shark	Carcharodon carcharias	Florida	liver	[3]	[3]	700– 7,000
Spotted eagle ray	Stoasodon narinari	Florida	liver	[3]	[3]	35
Cow-nosed ray	Rhinoptera bonasus	Florida	liver	[3]	[3]	675
Manta	Manta birostris	Florida	liver	[3]	[3]	200– 400

Sawfish	Pristis pectinatus	Florida	liver	[3]	[3]	900– 7,000
Congrio negro	Genyoterus chilensus	Chile	liver	[3]	[3]	1,000– 2,000
Cow shark	Unknown	Chile	liver	[3]	54–70	1,600– 3,000
Raya	Unknown	Chile	liver	[3]	30	13,000
Barn-door skate	Unknown	Chile	liver	[3]	52	4,000
Tollo	Galeorhinus mento	Chile	liver	[3]	20–53	1,200– 87,000
Peje-gallo	Callorhynchus callorhynchus	Chile	liver	[3]	28–41	700– 1,600
Pinta roja	Unknown	Chile	liver	[3]	7–41	1,300– 4,600
Spiny dogfish	Unknown	Chile	liver	[3]	41–46	6,000– 14,000
Six-gill shark	Unknown	Chile	liver	[3]	85	1,500
Bacalao	Polyprion oxigensis	Chile	liver	[3]	0.3–5.4	16,000–425,000
Sierra	Thysitops lepidopoides	Chile	liver	[3]	0.8	208,000
Unknown shark	Galeorhinus	Chile	liver	[3]	57	49,000
Merluza	Unknown	Chile	liver	[3]	25–37	3,000– 4,000
Hammerhead shark	Sphyrna zygaena	Brazil	liver	[3]	[3]	175,000–200,000
Unknown	Carcharias limbatus	Brazil	liver	[3]	[3]	50,000–125,000
Unknown	Carcharias lamia	Brazil	liver	[3]	[3]	50,000
Unknown	Odontaspis americanus	Brazil	liver	[3]	[3]	10,000– 50,000
Unknown	Isurus oxyrhynchus	Brazil	liver	[3]	[3]	25,000
Unknown	Rhinoptera jussieuri	Brazil	liver	[3]	[3]	3,000– 5,000
Unknown	Galeocerdo maculatus	Brazil	liver	[3]	[3]	1,000– 3,000
Unknown	Manta chrenbergii	Brazil	liver	[3]	[3]	3,000– 5,000
Sardinero	Eulamia aethalorus	Pacific-Mexico	liver	[3]	66–78	3,000– 16,000
Gambruso	Eulamia azureus	Pacific-Mexico	liver	[3]	68	17,500
Pilota	Eulamia galapagensis	Pacific-Mexico	liver	[3]	32–55	8,000–110,000
Puro	Eulamia velox	Pacific-Mexico	liver	[3]	69–79	20,000– 30,000
Puro	Scoliodon longurio	Pacific-Mexico	liver	[3]	68	50,000

[1] Vitamin D data for some of these species are included in Table 107.
[2] Per cent of round weight means the porportion of liver weight to the weight of the entire fish (undressed) expressed as per cent.
[3] The source from which information listed here was obtained did not supply data under this heading.
[4] Viscera indicates the contents of the body cavity, minus stomach, liver, and gonads.
[5] Offal indicates cannery trimmings, including head and viscera.
Source: U. S. Fish and Wildlife Service.

TABLE 107. VITAMIN D CONTENT OF OILS FROM FISHERY SOURCES.

Common name	Scientific name	Where caught	Source of oil	Vitamin D content in International units per g of oil[1]
Albacore tuna	Germo alalunga	Pacific	liver	25,000–250,000
Albacore tuna	Germo alalunga	Pacific	waste [2]	67
Bluefin tuna	Thunnus thynnus	Pacific	liver	20,000– 70,000
Yellowfin tuna	Neothunnus macropterus	Pacific	liver	10,000– 45,000
Skipjack tuna	Euthynnus pelayms	Pacific	liver	25,000–250,000
Bonito	Sarda chiliensis	Pacific	liver	50,000
Swordfish	Xyphias gladius	Pacific-Atl.	liver	2,000– 25,000
Mackerel, Pacific	Scomber diego	Pacific	liver	1,400
Halibut	Hippoglossus hippoglossus	Pacific	liver	1,000– 5,000
Halibut	Hippoglossus hippoglossus	Pacific	viscera [3]	100– 500
Sablefish	Anaplopoma fimbria	Pacific	liver	600– 1,000
Sablefish	Anaplopoma fimbria	Pacific	viscera	100
Lingcod	Ophiodon elongatus	Pacific	liver	1,000– 6,000
Lingcod	Ophiodon elongatus	Pacific	viscera	100– 200
Rockfish	Sebastodes sp.	Pacific	liver	300– 5,000
Cod	Gadus macrocephalus	Pacific	liver	85– 500
Ishinagi	Stereolepis	Pacific	liver	3,800
Barracuda	Sphyraena argentes	Pacific	liver	2,000
Black sea bass	Stereolepis gigas	Pacific	liver	5,000
Beluga whale	Delphinapterus leucas	Pacific	liver	50– 100
Grayfish (Dogfish)	Squalus suckleyi	Pacific	liver	5– 25
Grayfish (Dogfish)	Squalus suckleyi	Pacific	body [4]	29
Ratfish	Hydrolagus colliei	Pacific	liver	2– 5
Soupfin shark	Galeorhinus zyopterus	Pacific	liver	5– 25
Herring	Clupea pallasii	Pacific	body [5]	25– 160
Herring	Clupea pallasii	Pacific	liver	250
Pilchard	Sardina caerulea	Pacific	body [5]	20– 100
King salmon	Oncorhynchus tschawytscha	Pacific	liver	100– 500
King salmon	Oncorhynchus tschawytscha	Pacific	offal [6]	50– 150
Sockeye salmon	Oncorhynchus nerka	Pacific	liver	200– 600
Sockeye salmon	Oncorhynchus nerka	Pacific	offal	100– 300
Silver salmon	Oncorhynchus kisutch	Pacific	liver	100– 500
Silver salmon	Oncorhynchus kisutch	Pacific	offal	100– 200
Pink salmon	Oncorhynchus gorbuscha	Pacific	liver	100– 600
Pink salmon	Oncorhynchus gorbuscha	Pacific	offal	100– 300
Chum salmon	Oncorhynchus keta	Pacific	liver	100– 500
Chum salmon	Oncorhynchus keta	Pacific	offal	50– 100
Starry flounder	Platichthys stellatus	Pacific	liver	1,000
Rex sole	Errex zachirus	Pacific	liver	150
Skate	Raja binoculata	Pacific	liver	25
Mud shark	Hexanchus griseus	Pacific	liver	20
Snoek	Thyrsites atun (Euphrasen)	S. Africa	liver	500– 6,000
Snoek	Thyrsites atun (Euphrasen)	S. Africa	viscera	85
Stonebass	Polyprion americanus (Bl. and Schn.)	S. Africa	liver	700– 1,300
Stockfish	Merlucius capensis (Castel.)	S. Africa	liver	50– 380
Stockfish	Merlucius capensis (Castel.)	S. Africa	viscera	3
Kingklip	Genypterus capensis (Smith)	S. Africa	liver	85– 600
Halibut	Unknown	S. Africa	liver	1,000– 2,000
Cod	Unknown	S. Africa	liver	100
Ling	Genypterus blacodes	N. Z'land	liver	500
Yellowtail	Seriola dorsalis	Australia	liver	9,000– 17,000
Halibut	Hippoglossus hippoglossus	Atlantic	liver	2,000
Mackerel, common	Scomber scombrus	Atlantic	liver	750
Rosefish	Sebastes marinus	Atlantic	waste [7]	50
Dogfish	Squalus acanthias	Atlantic	liver	3

[1] Date on vitamin A content of most of these fish are to be found in Tables 105 and 106.

[2] Waste indicates offal from the cannery fish cleaning tables. The raw eviscerated fish is precooked prior to this cleaning operation, hence some of the tuna body oil has been lost from this waste before it is made into meal and oil.

[3] Viscera indicates the contents of the body cavity, minus liver, stomach, and gonads.

[4] Body indicates the entire body of the fish, minus the liver.

[5] Body indicates the entire body of the fish, including liver and viscera.

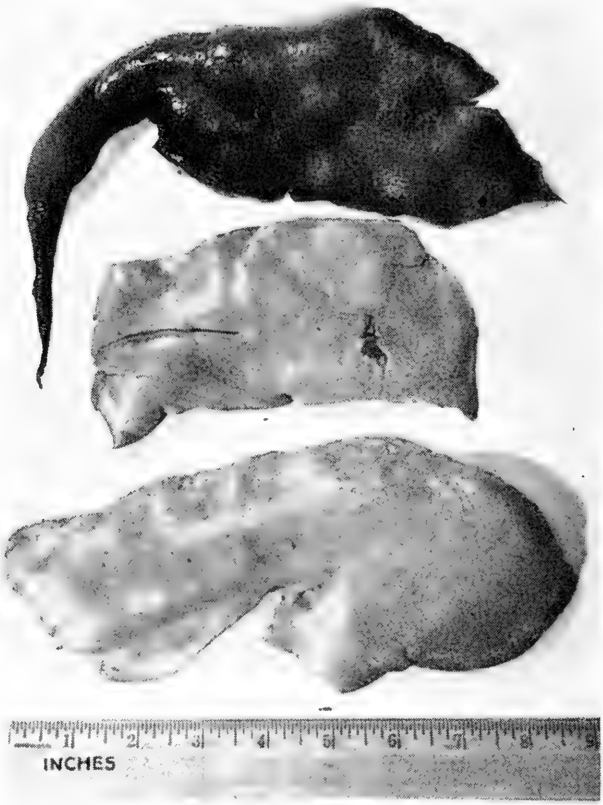
[6] Offal indicates the cannery trimmings, including heads, livers, and viscera, but not eggs.

[7] Waste indicates the entire body of the rosefish, minus fillets or edible portion; it includes head, backbone, skin, and viscera.

Source: U. S. Fish and Wildlife Service.

easily removed by a simple method of extraction; in others the oil is removed from the livers only after breaking up the molecule of protein composing the liver. In the latter case a more complicated method of extraction is required.

The viscera, including the stomachs and gonads of some species of fish, contain appreciable amounts of vitamin A; these are not ordinarily included when the



(Courtesy U. S. Fish and Wildlife Service)

FIG. 23–1. Ventral view of fish livers; top, rockfish; middle, lingcod; bottom, halibut.

livers are purchased unless specifically indicated by the buyer. Processing viscera, including the livers, is confined almost entirely to halibut and sablefish. The livers of other species are usually purchased free of viscera. The processes which have been developed for the extraction of vitamin A oils from livers are generally not applicable to viscera, and for this reason it is not generally considered economical to handle both in the same plant.

The center of production of vitamin A-bearing oils is on the Pacific Coast of the United States. The livers of the fish found in that area have a higher vitamin A content than those in any other coastal area of the United States. This has never been explained satisfactorily, but even similar species of fish livers vary to

a large extent between the east and west coasts. Some of the imported vitamin A livers are extracted elsewhere, but there is only minor production on the East and Gulf coasts.

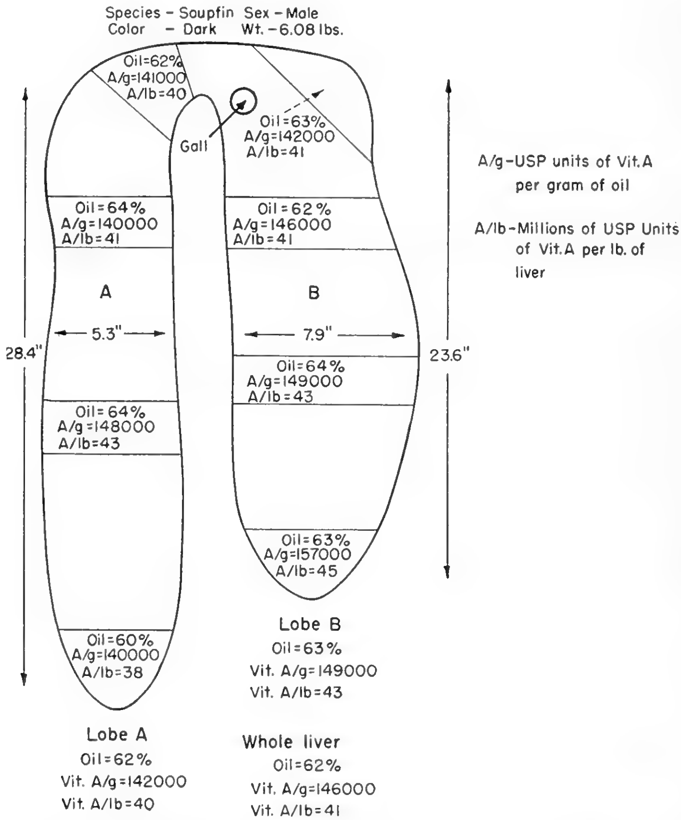


FIG. 23–2. Distribution of Vitamin A in a soupfin shark (*Galeorhinus zyopterus*) liver.

Methods for Processing Cod Livers

The most generally accepted way of extracting oil from cod livers is by means of a steam cooker. The method of applying the steam has been changed from time to time to meet the demand for a higher-grade oil. Low-pressure steam is piped into a tank containing the livers. The heat of the steam cooks the livers; it condenses, a layer of hot water is produced upon which the oil floats. The oil is then either dipped off or the tank is fitted with an overflow into an oil storage tank. Some liver oils are extracted at sea on board trawlers and schooners when they remain at sea for protracted trips.

Two Canadians, Labrie and Fangeri (1937), suggested an inexpensive, efficient method adapted to small-scale operations. This apparatus is of particular value to the small operator or isolated fisherman. A kettle steam generator is fitted with a

perforated tube. This tube is enclosed in a double cylinder arrangement, and the inside cylinder is perforated. When the inside cylinder is filled with livers, the kettle is heated. Water in the kettle is boiled and the steam passes through the perforated tube into the livers, releasing the oil which flows into the outside cylinder and is drained off from time to time.

Flotation Process. At Rimouski, Quebec, one plant is operating in which only cod livers treated with a patented compound (Hopkinson, 1935) known as "Aquacide" (mixture of organic aldehydes, alcohols, and acid) are used. The treated or preserved livers are brought from distant, more or less inaccessible points of production. The preservative appears to harden and "keep" the livers, which can be held in tight drums for several months prior to extracting the oil without appreciable loss of vitamin content.

This method is not applicable to untreated livers or to those of a number of other families of fish. The livers are removed from the drums, washed with fresh water, and put through a grinder; the ground mass is then passed through a colloid mill, which gives it a consistency approximating that of a thick paste. The product is conveyed into tall, cylindrical, open-top flotation tanks. The height of the tanks is nearly double the diameter; the walls are fitted with rectangular sight glass from the middle almost to the top. Inside each tank is an agitator for stirring; around the walls are perforated pipes at intervals to within a foot of the top. Warm water at about 120° F (40° C) is pumped in through the perforated pipes, and the agitator mixes the water with the ground fish livers, forming an oil emulsion. When the mixture nears the top of the tank, some additional cold water is run in from the top; soon the emulsion can be seen to break and the oil rises to the surface where it is drawn off. The small amount of water in the oil is removed by passing a thin film of the oil through a vacuum drier which operates continuously at a temperature of 75 to 80° F (20.4 to 20.7° C). At this stage any trace of preservative which remained after washing the livers is removed.

There are several critical points which make the flotation process yield almost theoretical. The size of the particle after grinding; the rate of agitation in the tank; the temperature and the rate at which the water is added are all quite critical, and are carefully controlled.

The dried oil is put through a separator where the last traces of liver pulp are removed. To meet the requirements for refined oil it is chilled to 32° F (0° C) and filtered at this temperature to remove the stearin. It is finally stored in enamel-lined drums under an atmosphere of nitrogen.

Removal of Oil by Sugar-Beet Residues. Dried sugar-beet residue is mixed with whole fresh livers for extraction of the oil in a patented process (Wentworth, 1938). This method is in use in one plant in Canada, and either cod or shark livers can be used in the process. The proportion of beet pulp to livers is governed to some extent by the condition of the livers, that is, the oil and water content and the degree of freshness. An average of 13 pounds of the dried beet pulp is mixed by means of a paddle mixer with 120 pounds of livers. It is not necessary to grind the livers unless they are particularly tough; some species of shark livers require grinding or mincing. After mixing for a few minutes it is possible for an experienced operator to make a test by squeezing a handful of the mass. If the oil is released easily, it is ready for pressing. The mass is placed in

cloth bags separated by boards and pressed by a hand-operated screw press. There is considerable loss of oil, but the efficiency compares favorably with the steaming process, or an average of 40 to 50 per cent of the theoretical yield. The refined oil is prepared by the cold process, as mentioned above. The press cake containing the liver residue, water, and beet pulp is dried and sold as cattle feed with high protein content and increased vitamin A and D potency.

The mechanics of the separation of liver oil by this method is not thoroughly understood. The theory is that the dried beet pulp has such a sufficiently high affinity for the water in the livers that it can break the emulsion of oil in the cells and absorb the water.

Cod Oil. The previous discussion has been limited entirely to cod-liver oil as it is used for pharmaceutical purposes. A second grade of cod-liver oil, known as "cod oil," is a recognized item in the fish-oil trade. It is usually a dark-colored oil with a disagreeable odor, and is prepared from cod livers which have partially or completely decomposed.

This grade of oil finds a market in those industries where fish body oil of all species is used. Much of the cod oil is used in the leather-tanning industry, and is often sulfonated for this purpose. As a "currying" oil it softens and lubricates the leather fibers. It is also used in the manufacture of paints, varnish, printing inks, oilcloth, and linoleum. The steel industry uses it for tempering springs and other articles made of steel.

Very little cod-liver oil of either the medicinal or lower grade is extracted in the United States. Practically all the oil used in this country is imported from either Canada or Iceland, and small quantities are brought from Norway. Medicinal oil is imported as a crude grade and the refining is done by the various users of this grade of oil.

Nutritional Value of Extracted Cod-Liver Residue

It has long been recognized that the pulp, or fibrous material remaining after the oil has been extracted from cod livers is a valuable ingredient for inclusion in animal feeds. And while no analyses are available on commercially prepared meals, Guttman (1950) has published analyses on laboratory samples. He found that the average properties of this meal or residue pulp contained the following ingredients:

Moisture	5.1 Per cent
Total nitrogen	10.7 Per cent (moisture and oil free basis)
Free amino acids	4.0 Per cent (expressed in nitrogen)
Ash	7.6 Per cent
Copper	0.00033 Per cent
Iron	0.02 Per cent
Vitamin B_1	2.7 mg. per lb.
Vitamin B_2 (riboflavin)	18.0 mg. per lb.
Niacin	50.0 mg. per lb.
Pantothenic acid	18.0 mg. per lb.
Total APF activity	1.4 mg. per lb.

He estimates that at the present price of 20 cents per mg., the APF activity alone is worth $560 per ton when calculated on this basis, disregarding the other valuable nutritional factors.

Extraction of Grayfish and Shark-Liver Oils

The liver of the grayfish (dogfish) found on the Pacific Coast contains an average of 15,000 U.S.P. units of vitamin A per g, while the same species on the Atlantic Coast contains only 2,000 to 3,000 units of vitamin A. This accounts for the fact that this species has never been sought for the vitamin A-bearing oil on the Atlantic Coast. There is no satisfactory explanation for this phenomenon.

The steaming process is used extensively on the Pacific Coast to remove oil from livers containing 50 per cent oil with a vitamin A potency of 8,000 to 15,000 U.S.P. units. The coarsely ground livers are placed in a tank and live steam is admitted for cooking. In a few plants the cooking tank is fitted with a mechanical stirring apparatus to increase the agitation of the liver particles and to facilitate a more even cooking. The oil released may be separated from the water and liver residue by gravity; but since most plants are equipped with a 3-phase centrifuge, this method is preferred. In some plants the water phase of the material separated by centrifuge is washed with low-potency vitamin A oil, such as sardine or other low-potency body oil, to remove the last traces of vitamin A from the water before it is discharged.

Harrison and Hamm (1941) found that it was possible to remove 80 per cent of ground dogfish-liver oil containing 5,000 U.S.P. units of vitamin A by means of a basket centrifuge. However, the potency of the oil was considerably less than that indicated by the assay of the livers. Upon acid digestion of the residue, these workers obtained an equivalent of 13.5 per cent of the liver oil with a potency of 15,200 U.S.P. units of vitamin A per g. Bailey (1941) suggested that a coagulation of the liver protein by means of calcium chloride would release the oil. It was found that this method required two stages to remove completely the oil and vitamin A content of the livers.

Grayfish (dogfish) which had been initially cooked in a retort at steam pressures of 30 to 100 pounds are more easily extracted than fresh livers. This treatment appears to inactivate the enzymes of the livers and is recommended where the livers are to be shipped to distant points for the final extraction of vitamin A oil.

Alkali-Digestion Method

Livers of low oil concentration and high vitamin A potencies, including halibut, rockfish, tuna, lingcod, etc., are most easily extracted with a low concentration of sodium hydroxide (1 to 2 per cent by weight) or 2 to 5 per cent sodium carbonate (Young and Robinson, 1938). The livers are first ground in a meat chopper or disintegrator to hasten the reaction. The temperature is held at 180–190° F (82–88° C) until the solids of the liver are in the liquid stage, entirely releasing the oil. The entire mass is agitated to increase the efficiency of the chemical reaction and release the oil. The liquor is then passed through a 3-phase or sludger-type centrifugal, which separates the oil in the form of an emulsion. The pH of the emulsion is then adjusted to a suitable point so as to recover the oil as completely as possible. Breaking the emulsion makes possible the delivery of a marketable oil after it is passed through a properly adjusted purifying-type centrifuge. In cases where the purified oil contains suspended soaps or excess free fatty acids, further refining is necessary.

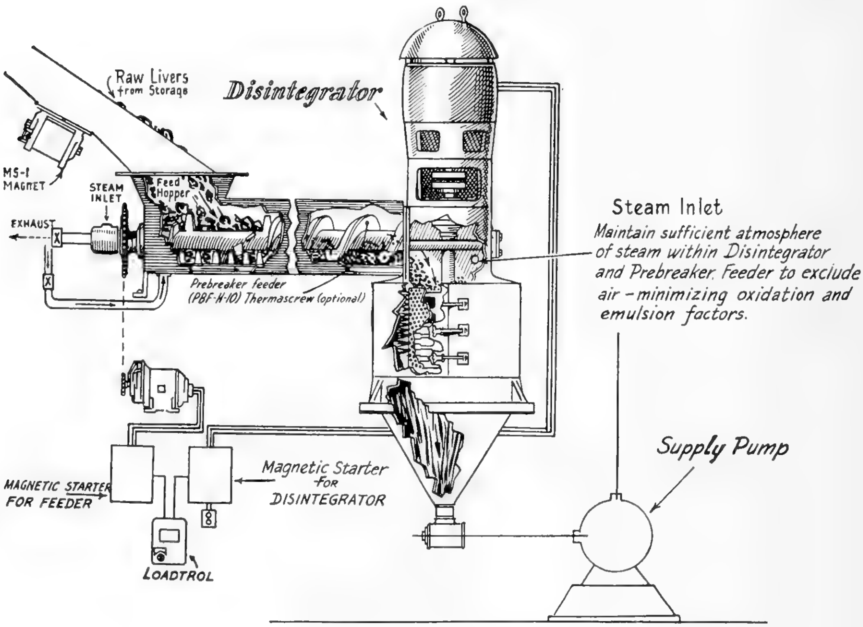
The water phase, separated by the first centrifugal, contains particles of liver tissue, some vitamins adsorbed on the soaps, and some oil; this mixture is called "wash oil." The vitamins in the "wash oil" are usually recovered by mixing it with a low-vitamin edible oil at 175° F (80° C), and by centrifuging. The washing process may be repeated until the vitamin A potency is so slight that it is no longer profitable to repeat the washing (Young and Robinson, 1938).

It is obvious that many variations are possible in the above procedures. Some oil processors have found by experience that certain modifications require varying conditions. For reasons which can be determined at the individual plant the steps in the process are adjusted to the conditions.

A modification of the alkali process (patented by Herbert Hempel in 1939) involves use of a different type of alkali to neutralize the fatty acids which develop as the livers decompose. The alkalies suggested were borax, trisodium phosphate, and ammonium hydroxide. Specific adjustments of the pH of the livers to insure complete neutralization of the fatty acids is recommended. These procedures are similar except for this difference in alkalies.

Enzyme- and Alkali-Digestion Process. This process involves the use of both alkalies and peptization to complete the digestion of the liver cells for the release of the oil. Brocklesby and Green (1934 and 1937) suggest the following procedure:

The livers are minced or disintegrated and a volume of water equal to that of the livers is added, together with sufficient hydrochloric acid to give the mixture a pH of 1.2 to 1.5. A pepsin solution containing 0.5 per cent by weight of the livers



(*Courtesy Edw. Renneburg and Sons Co.*)

FIG. 23–3. The disintegrator finds many uses of value in the liver oil and the fish meal plant.

is added. The digestion is then carried out at a temperature of 110 to 120° F (43–49° C) for 36 to 48 hours, depending upon the completeness of digestion of the liver material. At the end of this period a sufficient quantity of saturated sodium carbonate solution to adjust the pH to approximately 9.0 is added. The temperature is raised to 175° F (80° C) and digestion is continued for exactly one hour.

It is suggested that this method is superior in the event that exceptionally fresh livers are being handled. In this case it is often difficult to separate the oil from the other components of the emulsion. The theory advanced for this is that the enzyme action and the addition of a mineral acid stops the action of fat-splitting enzymes usually present in the livers. These are responsible, to a considerable extent, for the formation of free fatty acids.

Extraction of Livers of Low-Oil Content and High-Vitamin A Potency. This process is useful in handling such livers as halibut, tuna, and sablefish. The minced or disintegrated livers are covered with a low-potency oil (pilchard or grayfish are extensively used for this) and the temperature is raised to 212° F (100° C). Heating is continued for periods ranging from 30 to 60 minutes, with constant mechanical agitation. At the end of the digestion the enriched oil is separated mechanically or drawn off after the solids have settled. Repeated extractions improve the efficiency of the process and recover the vitamin A almost completely. This method can be used at liver receiving points. The cooked mixture can be transferred to the oil refining plants, where the process is completed.

Solvent Extraction Methods

The use of solvents for the extraction of vitamin A oils from fish livers has been largely replaced by the alkali-digestion methods. This is chiefly because of the greater care needed in the process and the difficulty in obtaining solvents free from impurities, particularly peroxides, which cause deterioration of vitamin A. The use of solvents results in darker colors, higher viscosities, and foreign odors.

The livers to be solvent-extracted are steamed at 158–167° F (70–80° C) from 30 to 45 minutes with continual stirring. When the cooking is completed they are then drained as completely as possible. The livers are then placed in tight containers and protected from oxidation by covering with carbon dioxide gas or paraffin. After this they are cooled to −10° F (−23° C) or lower, and are extracted with diethyl ether, free from peroxide or some similar solvent. The extract is filtered and the oil is recovered by vacuum distillation. The solvent is recovered for reuse. This process is covered by a patent (Nielsen, 1937).

Condition of Livers and Processing Procedure

Obviously the degree of freshness of the fish livers has to be given consideration when deciding upon the type process most likely to produce a high-grade vitamin A oil. Fishermen are conscious of the fact that since the livers are purchased on the basis of the vitamin A potency, it is to their advantage to handle them so that as much of the original vitamin content as possible is retained. The livers are removed from the fish and immediately packed in clean 5-gallon telescope-top tin cans and packed in ice.

When the livers are landed they are purchased on the basis of the vitamin A potency of each can of livers. The processor then must decide the most efficient

method for producing the highest potency oil possible from the livers. If he is not ready to proceed with immediate extraction of the livers, he can place them in a freezer and store them for several months without serious loss of vitamin A. Frozen livers stored at a temperature as low as $-20°$ F ($-29°$ C) undergo only slight change since the tight can protects them from the air and dehydration.

In trade practice the term "fresh" is applied to all raw material which has not been frozen or preserved by other means. If the livers have not been preserved, they have undergone some decomposition; this tends to cause the formation of free fatty acids, which will be carried into the finished oil. It is also possible for the livers to develop odors of decomposition which will eventually appear in the finished product, and thus lessen its value.

Viscera

Some Canadian producers of vitamin A oils use the viscera as well as the livers. This has been attempted from time to time in the United States by pharmaceutical firms, etc. One of the chief difficulties to overcome has been the high moisture content of the viscera. Since the use of the viscera is not practiced generally in the United States, probably due to the low recovery of vitamin A, it is not of commercial importance.

Preservation of Livers

Freezing and Storing. The most generally used method of preserving livers is by freezing. When the livers are removed from the fish on board the vessels, they are packed in 5-gallon square cans, with a telescope-type round cover. The cans are filled as nearly full as possible so that the enclosed air is reduced to a minimum. This is to prevent oxidation of the oil by entrapped oxygen of the air. The completely filled cans are closed and packed in cracked ice in the hold of the vessel. When it reaches port, the cans are removed immediately to the freezer if the oil is not to be extracted at once. If the processor purchases more livers than he can handle for a few days, he may take them out of the 5-gallon cans and place them in a large 50-gallon drum fitted with a clamp top and freeze them. The usual freezer temperature is $-20°$ F ($-29°$ C) or lower. At this temperature the enzymatic and bacterial action is either very slow or completely arrested. The livers may be held for several months in frozen storage without any considerable increase in the fatty acid content.

Since vitamin A is probably contained in the protein of the liver as well as oil, the rupture of the cellular structure has little, if any, effect upon the final recovery. Freezing may release a large portion of the oil which will float to the top of the container, when the livers are defrosted. This increases the difficulty of obtaining an accurate sample for determining the vitamin A potency.

In planning for the processing of frozen livers it is necessary to defrost a sufficient supply to keep the plant in operation throughout the day. If for any reason the process is slowed down, it may be found that too great a quantity of livers has been defrosted, and thus a problem of deterioration is created.

Preservation by Salting. Considerable quantities of livers are landed in ports where there are no facilities for freezing. In many of these there is not even sufficient ice for adequately storing the livers on board the vessels until they are landed. In this case salt is usually used as a preservative. This method is common

in Mexico, Central and South America, Africa, Europe, Japan, and the Caribbean Islands. Many of the livers produced in these areas are shipped to the United States for final processing.

The purchasers of salted livers have set out a series of instructions for use by those who produce them in more or less remote areas. To preserve the livers adequately they must be thoroughly cleaned, with removal of the gall bladder, and promptly packed in a tight container. They are required to be cut into pieces not more than 3 inches thick and evenly salted with 10 per cent salt by weight. The containers should have tight covers and be packed as full of livers as possible so that there will be a minimum of enclosed air. If proper care is used in handling livers in this manner, they may be stored at air temperature over periods of several months without serious loss of vitamin A potency.

According to some reports, it has been found that salted livers require a larger amount of alkali for digestion. Whereas fresh livers require 2 to 3 per cent alkali for digestion, salted ones require 8 per cent. This increase in alkali leads to excessive formation of soap, which in turn is difficult to remove from the oil. In the pepsin digestion process similar difficulty is experienced, but it is not so pronounced.

Formalin as a Liver Preservative. Formalin has been used as a preservative for all types of livers. If the percentage of this chemical is in excess of 0.25 per cent by weight, the livers become hardened to such an extent that it is impossible to extract the vitamin A. Formalin causes the formation of small hard lumps which are resistant to all known methods of extraction. In the case of shark livers this applies to the patented compound "Aquacide," and its use on these livers is not recommended. In the case of shark and other high-potency livers a preservative in the powdered form is suggested.

Another preservative which can be used for ground shark livers is composed of 9 parts sodium carbonate, 1 part sodium nitrate, and 10 parts water by volume. This solution is used in the proportion of 5 per cent by weight of the ground livers. Since the sodium carbonate has a mild alkaline reaction, it does not increase the difficulties of extraction when the alkali process is used.

Factors Controlling Quality of Vitamin A Liver Oil

Some vitamin A liver oils are classed as medicinal products. The quality is regulated by strict government inspection and tests. Only that oil meeting the requirements is permitted to be sold for medicinal uses. These regulations apply not only to the oil used in human nutrition, but also to that going into the markets for use in animal diets. The requirements of the U. S. Pharmacopoeia XIII are that cod and halibut livers used in the preparation of medicinal grades of oil be fresh or suitably preserved. The liver oil industries of Canada, Newfoundland, Iceland, and Norway have very rigid standards and are under strict governmental supervision and inspection.

Oils which contain more than 0.3 per cent moisture and 0.03 per cent sediment, other than stearin or waxes, require further refining. Moisture in the oil always carries some protein which will decompose and impart a putrid odor. The moisture and protein mixture is also an excellent medium for the growth of bacteria, which will extend into the oil and cause serious deterioration.

Light and atmosphere are to be avoided, as far as possible, since both hasten

oxidation, which in turn causes an increase in the fatty acid and peroxide values and a resulting loss of vitamin A potency. All containers for use in shipping oil must be air-tight and filled as full as possible. The storage temperatures of the oil are held near 35 to 40° F (2 to 5° C) since changes in the oil are retarded at this range. Some refiners displace the air above the oil in containers with inert gases, such as nitrogen and carbon dioxide.

Extraction of Livers by Solvents

The early attempts of the processors to make use of solvents to remove the oil from high-potency livers were not highly successful. The solvents used removed not only the oil and vitamin A, but also some coloring matter which was difficult to eliminate. Such solvents as ether often contained peroxides as impurities, which hastened the oxidation of the oil during the extraction period. The elevated temperatures for the prolonged periods required for complete removal of the solvent were another factor contributing to oxidation and loss of vitamin. Even refining by means of alkali treatment did not completely overcome the discoloration, though it did remove the fatty acids.

Later the processors took advantage of information gained by the extractors of some vegetable oils and found solvents which are not so objectionable as those used earlier. At present, use of the solvent process for the extraction of oil is gaining popularity as a result of the development of new, more efficient solvents and the availability of more highly purified ones than those previously used. These eliminate many of the difficulties previously mentioned in solvent extraction processes.

Processing by Alkali Digestion

The most generally used method by far for the recovery of vitamin A is the treatment by the alkali digestion process or some of its many modifications. The nature of this process itself serves to inactivate the enzymes and reduce the fatty acids of the refined oil. The amount of alkali used is carefully adjusted and chemically controlled so that it is never more than slightly in excess. This results in holding the formation of emulsions to a minimum and prevents the excessive loss of adsorbed vitamin A in the water phase.

Research is under way for the investigation of oxidation of vitamin A oils produced by this method and held for long storage periods. The loss of vitamin A potency in these oils is one of considerable economic importance to the industry. The condition of the livers has been found to be of major importance as a contributing factor in the keeping quality of the final product.

Processing Equipment

Butler (1948) gives the following suggestions for the establishment of a liver-oil extraction plant for the processing of high vitamin A livers:

"Many types of equipment can be used for the preparation of vitamin oils. In the selection of the equipment for a particular plant some of the items to be considered are: (1) kind and volume of material, (2) process contemplated, (3) availability and relative cost of power and heat from the various sources such as electricity, steam, water power, internal combustion engines, etc., (4) amount of mechanization and automatic control, (5) cost and availability of labor.

"Many of these factors may be difficult to evaluate accurately in advance for the localities being considered. Even estimates made on the spot at the time the contemplated business venture is being initiated will be subject to considerable error. Therefore, only the factors for which a fairly close approximation is possible are enlarged upon here.

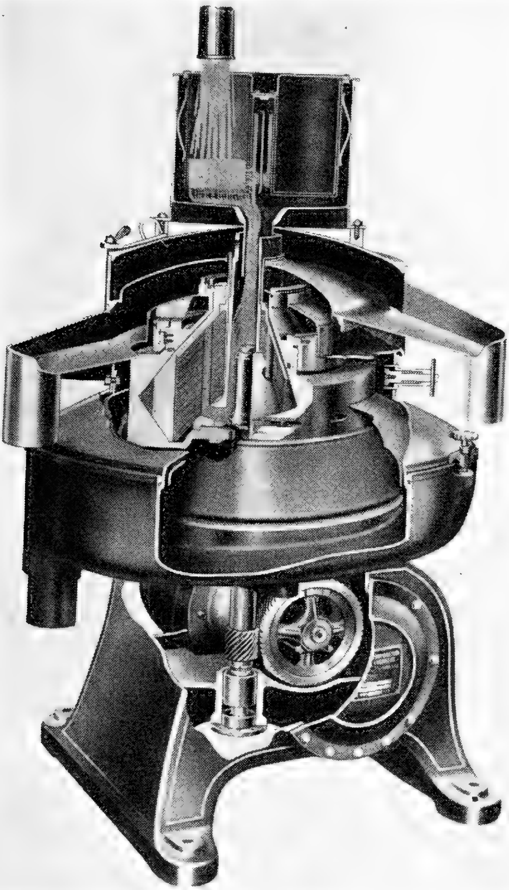


Fig. 23–4. The internal construction of the Nozljector is shown by the cut-away view of this machine.

(Courtesy Sharples Corp.)

Steaming Method

"Let us assume the simplest and most inexpensive conditions, within reason, and set up the approximate equipment requirements for a given capacity of production. The steaming process for low potency shark livers will fall into this category.

"The livers should be ground in either a conventional meat grinder or in a hammer mill. A vertical hammer mill, capable of disintegrating approximately 2 tons of liver per hour, will cost from $1,200 to $1,800. Smaller sizes would be somewhat less expensive.

"The ground livers should be transported to the cooking tanks by means of a gear pump to minimize churning of the material. A suitable pump to handle the output of the above-mentioned grinder costs $150 to $300. A trap basin should be installed in the

pipe-line between the outlet from the grinder and the pump to minimize the amount of rock and tramp iron introduced into the gear pump. A shear pin of sufficiently small diameter is often advisable to protect the pump in case such solid materials do travel that far. Valves on the liver pipe-line should be self-cleaning and nonclogging.

"Cooking tanks may be fabricated of wood or iron, depending on the desires of the processor and the availability of material. As an example of the relative cost in the Seattle area for tanks of approximately the same dimensions and of 1,000 gallons capacity, those made of iron cost approximately $100 and those of wood cost $65. If heating is to be direct steam, the only cost, other than piping, valves, etc., might be for an automatic steam controller at $50–$100 per tank to regulate the temperature of the cook at the desired temperature. If cooking is accomplished by indirect steam heating, there will be the added cost of pipe coils. Agitation may be by a portable electric mixer, a fixed side-entrance stirrer, or a stirrer fixed on top of the tank and driven by a chain or belt activated by suitable shafting and gears. Portable stirrers are available in various horsepower ratings and motor speeds. One brand of stirrer having a 1½-horsepower motor and operating at 1,750 revolutions per minute costs approximately $185. The same brand with a ½-horsepower motor costs approximately $110.

"Several variations in the application of centrifugals for the separation of fish-liver oils are in use by the processors. If the steaming process is used on a small scale, it is possible to get fairly high oil recovery by allowing the material in the cooker tank to settle until the upper or oil layer separates before it is drawn off to be processed in the oil purifier or centrifuge. An imperforate basket centrifuge may also be used to separate the liquid constituents from the solids prior to the final purification of the oil. For larger operations the entire contents of the tank are first passed through the sludger centrifuge to remove the wet oil from the solids; the wet oil is then finished in the purifier centrifuge.

"There are two principal manufacturers of the centrifugals now being used in the fish-liver oil industry. Each company manufactures the 3-phase or sludger-type machine, designed to accomplish the continuous preliminary separation of the cooked or digested liver material into (1) an emulsion of oil, water, and fine solids and (2) a sludge of water and coarse solids. The larger centrifuge of this type has an approximate capacity of 1,500 to 3,000 gallons of liquor per hour. The actual performance will be determined by the character of the material to be separated, and there may be some variation in capacity from one lot of material to another. The sludger of this capacity range costs $6,000 to $8,000, depending on whether stainless steel construction or standard equipment is ordered.

"The second machine—the oil purifier or polisher—is designed to recover the oil in a marketable form from the oil-water-fine solids emulsion of the sludger-type centrifuge. These purifier machines are available in several sizes. The approximate costs for the usual industrial models are $1,800, $2,400, and $3,500.

"Centrifuges may require a rather large supply of hot water for satisfactory performance, especially if the sludger machine is used. Therefore, there should be provision for an adequate supply of water at 180–190° F (82–88° C).

"The boiler capacity required for liver processing varies considerably with the process and plant equipment, but a rough estimate would be 10 boiler horsepower per 1,000 gallons of cooker capacity. Boiler costs are dependent on type and local rates. A 10-horsepower boiler suitable for a fish-liver plant should cost approximately $500.

"Plants processing large amounts of livers will need a gear pump to move the oil from the centrifuge to the tanks used for storage or for blending and mixing. A portable stirrer or other agitator is required for these tanks, and steam coils are usually desirable to warm the oil sufficiently to facilitate mixing in case it has become viscous or partly solid at lower temperatures.

Alkali Digestion Method

"Equipment for the alkali digestion method of processing is somewhat different and more elaborate. The grinder, liver pump, and cooker tanks are similar, except that since the livers are usually diluted with an approximately equal quantity of water twice as many cooker tanks are required for the same capacity as with the steaming method. Agitator requirements are practically the same for the cooker tanks, except that if portable stirrers are used more units should be available so that processing is not delayed in case digestions require longer to complete than had been planned. If the wash-oil technique is to be employed, several additional tanks and stirrers will be needed to accommodate the water from the digestions. Usually a pump is used to transfer the water discharge from the centrifuge to the wash-oil tanks. By means of a second pump the contents of the washing tanks are returned to the centrifuge. If it is so desired, suitable piping arrangements may be made to use one pump for a series of tanks for either cooking or washing. The wash-oil tanks should have some provision for maintaining the temperature of the liquor at about 180° F. This may be done by either direct or indirect heating with steam.

"The alkali process requires a close control over the pH of the liver mass during the digestion period. Several companies make equipment which measure pH. A small, portable, industrial model costing approximately $150 may be used; or the more elaborate, automatic recording model is available for approximately $750.

"With the alkali process both the sludger and the oil-purifier centrifuges are necessary unless only small amounts of materials are to be handled. A surge tank equipped with stirring and steam heating facilities should be available to receive the skim from the sludger. Any treatment to facilitate the breaking of the emulsion in the skim liquor may be accomplished in this tank before the liquor is passed to the oil purifier.

"When livers that are expected to yield higher potency oils are processed, the oils are usually collected in separate drums or tanks in accordance with the anticipated potency and the species from which the livers are derived. The wash oils are kept similarly segregated. Sufficient storage facilities must be provided for these lots of oils until they are ready for shipment."

Sampling of Livers

Nearly all livers are purchased by the processors on the basis of the vitamin A content. When the livers are landed at port, the cans are opened and the contents examined to determine the species of liver, its color, and condition as to freshness. An experienced buyer can make an approximate estimate of the vitamin content by this preliminary examination. In many cases the livers are sorted according to species, color, and condition of freshness at this point. Since fishermen are usually anxious to receive payment as soon as possible, the livers may be purchased on the basis of this estimate.

More often this procedure is not satisfactory for either party concerned, and a chemical analysis is made to determine more accurately the amount to be paid for the livers. An ingenious liver-sampling device is in use in most points where livers are landed. The sample is composed of several (usually five) vertical plunges of the sampler through the contents of the can. These borings are located one in each corner of the can and one in the center. The larger 52-gallon drums of livers may be sampled with the same apparatus, and usually more borings are made.

(Courtesy U. S. Fish and Wildlife Service)

FIG. 23–5. Samples of fish and shark livers are obtained by means of a specially designed device. The samples are analyzed in the laboratory for vitamin A and oil content.

TABLE 108. CHARACTERISTICS OF COD AND OTHER LIVER OILS.

	Specific Gravity at 59° F (15° C)	Free Fatty Acids, Per Cent	Saponification Value	Unsaponifiable	Iodine Value	Butyrorefractometer	
Cod (West Coast, Scotland)	.9248	0.20	186.0	1.06	153.7	75.7	66.7
Cod (unknown)	.9247	0.19	185.1	1.02	156.5	76.0	—
Cod (East Coast, Scotland)	.9263	1.20	187.9	1.04	167.3	78.0	69.0
Ling	.9240	0.34	187.2	1.00	151.8	75.0	—
Hake	.9256	1.05	190.7	1.38	154.0	76.0	—
Coalfish	.9261	0.27	187.2	1.14	161.1	77.0	—
Whiting	.9290	0.65	187.9	1.06	184.2	81.0	72.0
Haddock	.9290	2.37	187.2	1.30	186.4	81.0	72.0
Skate	.9298	0.33	187.9	1.08	191.1	82.5	73.5
Dogfish	.9179	Trace	169.7	8.40	126.4	71.2	62.5

TABLE 109. UNSAPONIFIABLE MATTER IN COD-LIVER OILS.

	Color	Unsaponifiable	Observer
Medicinal	Reddish yellow	0.54	Fahrion
"	Yellow	1.08	"
"	"	0.87	Thompson and Ballantyne
"	Pale yellow	1.44	Fahrion
Steam rendered medicinal	" "	0.61	"
" " "	Almost colorless	0.64	"
" " "	Pale yellow	0.98	"
Steam rendered medicinal Japanese		2.3–2.8	Bull

Laboratory Analysis

The U. S. Pharmacopoeia formerly required all vitamin A analyses to be based upon laboratory rat assays. This method is slow and costly and not readily adaptable to commercial practice. In order to overcome the delay in the determination of the value of livers or oils an instrument has been developed to replace the biological assay with laboratory animals. The assay of livers by use of this instrument is rapid and when multiplied by the factor 1,600, the results are sufficiently accurate to be acceptable to the Pharmacopoeial Association in its volume of regulations XIV which has recently been released. The assays for vitamin A by means of the spectrophotometer are now official and generally acceptable for purchasers and sellers of oils and concentrates.

Vitamin A is known to absorb ultra-violet light, and the instrument for the measurement of this absorption is known as a photoelectric spectrophotometer. The amount of light absorbed by a solution of the oil is measured and the vitamin A is calculated. The schematic diagram, Figure 23–6 indicates the optical construction of the instrument. There are a number of instruments of different makes available but operate on a similar absorption, which is based on the light absorption faculty of the vitamin A.

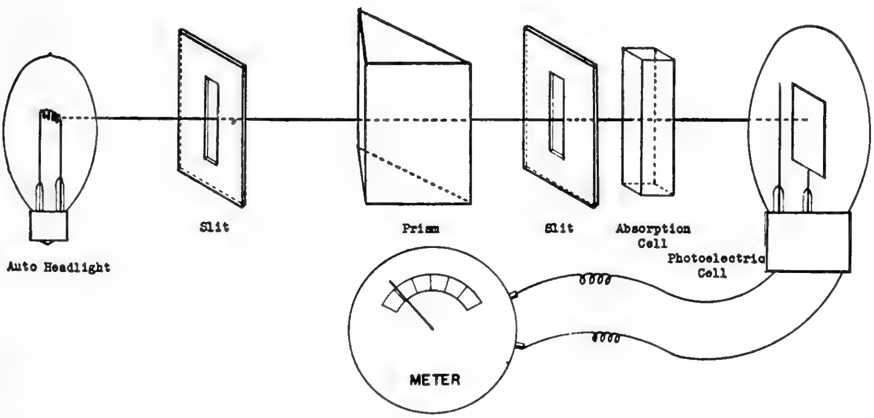


FIG. 23–6. Schematic drawing of operating principles of the photoelectric spectrophotometer.

Calculations Involved in Vitamin A Determination

Sanford (1948) has developed a method for the rapid determination of vitamin A in fish livers:

"In nearly all transactions involving fish livers the livers are sold on the basis of the number of millions of units of vitamin A per pound of liver. This figure is calculated from the data obtained from the oil and vitamin A analysis. A discussion of the method of making this calculation follows:

"The oil content of the livers is reported as a percentage based upon weight. For example, one lot of soupfin shark livers analyzed 62.3 per cent oil. This meant that, on the average, 62.3 pounds of oil were contained in every hundred pounds of this particular group of soupfin shark livers.

"Vitamin A potency of liver oil is reported as the number of units of vitamin A contained in one g of the oil. In the analysis of the soupfin shark liver just mentioned it was found that 1 g of oil contained 116,300 spec. units of vitamin A. It may seem strange that the potency of the oil is reported in grams when most common materials are weighed in pounds and ounces. However, the chemist has found it convenient to use the metric system in the laboratory, and he naturally reports his results in the units of measure in which he ordinarily works; but, except for making the labor of an additional multiplication necessary the reporting of vitamin A on the gram basis causes no particular difficulty.

"Assuming then that the oil content and oil potency have been obtained from a chemical analysis the first step is to calculate the number of units of vitamin A in a pound of the oil. Since there are 454 (or more accurately, 453.6) grams to a pound, this can be done by multiplying the number of units in 1 gram of the oil by 454. As an example, oil from the soupfin shark just mentioned would have yielded 52,800,200 units per pound as follows:

"$116{,}300 \times 454 = 52{,}800{,}200$ spec. units of vitamin A per pound.

"This gives the oil potency or the number of units per pound of oil. Since only a part of the liver is composed of oil, it is necessary to multiply the oil potency by the fractional amount of oil in the liver to get liver potency. To do this it is first necessary to convert per cent into a decimal, which can be done by dividing per cent by 100 as follows:

$$62.3 \text{ per cent} = \frac{62.3}{100} = 0.623 \text{ parts of oil per unit weight of liver.}$$

"Hence, liver potency is obtained by multiplying oil potency by this figure:

$$52{,}800{,}200 \times 0.623 = 32{,}894{,}524.6 \text{ spec. units of vitamin A per pound of liver.}$$

It is conventional to report liver potency in terms of millions of units per pound. Therefore, the number of units per pound is divided by a million as follows:

$$\frac{32{,}894{,}524.6}{1{,}000{,}000} = 32{,}894{,}524.6 \text{ million spec. units of vitamin A per pound of liver.}$$

"This is a cumbersome figure which can be simplified if the factors involved in its determination are considered. That is, if an independent attempt were made to redetermine the amount of vitamin A in these livers, the experimental error is such that these figures could not be reproduced again exactly. Experience has shown that any figures beyond the first four are meaningless. Therefore, these excess figures can be dropped and the vitamin A potency of the livers reported as 32.89 million units per pound of liver."

Chemical Control in Oil Production

Since the success of a vitamin A oil processor depends upon so many variable factors, practically all those engaged in this industry employ a staff of trained

chemists. The laboratories of these establishments act as process supervisors and also conduct research into improvement of the methods of extraction and preservation. It is difficult to obtain accurate information as to the exact methods employed by a given processor in handling the livers his buyers have purchased since dealing with the livers of different species as well as those from the same species under different circumstances of freshness, etc. requires different treatments. These variations in the processing methods are learned chiefly by experience, and are not divulged lest they fall into the hands of competitors.

The success of the entire operation of recovering the greatest possible yield of vitamin A from the raw material at hand is the responsibility of the chemist or chemical engineer in charge of the laboratory. The control laboratory is valuable in the disposal of waste materials which result from the process of oil recovery. They contain liver particles and other protein material which would constitute a health hazard if discharged into a sewer or open water without pretreatment. This pretreatment of waste material is dependent, to some extent, on the process used in removing oil from the livers. In many localities arrangements have been made to treat the waste material along with the regular sewage disposal, where there are no interfering ingredients in the waste.

As in many manufacturing processes there are volatile products of disagreeable odor, and it is imperative that these be disposed of so that they do not become a public nuisance. Most of the vitamin A extraction plants handle this problem by means of a washing tower which serves to remove the objectionable odors with a series of cold water sprays as gases rise through the tower. In some installations the volatile matter is recirculated through the furnace, where the odors are burned and eliminated.

The Capsulating Process

High potency vitamin A concentrates are more easily handled if they are in capsule form. If these concentrates are sold in liquid form in dark-colored glass bottles for home use, the loss of vitamin potency through oxidation is considerable after the bottle has been opened. The pharmaceutical houses have found that the most satisfactory method of distributing the concentrates is in a single dose in the form of an easily swallowed capsule. With the capsule it is possible to include other vitamins in addition to A, which results in a single capsule containing multiple vitamins and of various predetermined potencies. All vitamin concentrates are carefully assayed before being capsulated.

The most common method of capsule manufacture is one devised by R. P. Scherer (1933). In this method gelatin, glycerin, and water, in about equal parts, are thoroughly mixed. The mixture is next heated at 160° F (70.1° C) in a thermostatically controlled "Monel" metal or stainless steel vessel, where coloring matter may be added. When the cooking process is completed, the gelatin mixture is placed in the reservoir of the capsulating machine. Two ribbons of the mixture are extruded from slits, and pass over two large forming rolls. The ribbons are then passed through a mineral oil bath over a guide roll, and then against one another between a pair of die rolls. A heated injection wedge is fitted between the die rolls and between the ribbons. An accurately measured quantity of vitamin concentrate is forced between the ribbons from a small opening at the bottom of the wedge. The pressure applied to the concentrate forces the ribbons to conform

to the pockets in the die rolls, each ribbon forming one-half the capsule. The pressure of the die rolls seals the ribbons together, completing the capsule containing a globule of the concentrate. The globule is then punched from the ribbon and the finished capsule is cooled by a stream of air and washed in a bath of naphtha to remove the coating of mineral oil. The completed capsules are collected in trays for bottling, or stored for future use. The capsules are prepared at a rate of 60,000 to 75,000 per hour at a cost of approximately 10 cents per 100. This method has almost universal use in the capsulation of vitamin concentrates.

Concentration of Vitamin A

Saponification Method. Many patents have been issued covering processes for the concentration of vitamin A in fish-liver oils. These contain descriptions of techniques and physical and chemical methods for separating the unsaponifiable material in which the concentrate is found. The agents used and concentrations and temperatures are also contained in the patent literature.

The process in general consists of splitting the triglycerides of oil into glycerol and fatty acids, which are then combined into soaps. Unsaponifiable material containing vitamin A is then separated by means of solvents. The methods used to complete this separation involve alkalies, enzymes, acids, or synthetic organic catalysts.

The saponification method is most generally used by most of the processors. One of the deciding factors in treating liver oils by this method is the percentage of unsaponifiable material contained in the oil. An oil having a high percentage of unsaponifiable material and a low vitamin A potency cannot be converted into a concentrate by this method.

According to the U.S.P. definition, a concentrate is one in which the potency of vitamin A is 200,000 units or more per g. Some species of shark livers cannot be concentrated above 50,000 units because of the high unsaponifiable fraction in the oil. Such oils as these are usually concentrated further by one of the other methods.

Concentration by Molecular Distillation. Molecular distillation of products of high molecular weight has been available as a laboratory tool for many years. It was not until 1934 that real progress was made toward adapting laboratory methods to commercial processes. This resulted from research on high-vacuum photographic film drying and the development of high-vacuum condensation and fractionating pumps.

The presence of noncondensable gases in high molecular weight compounds exerts a definite retarding influence on their distillation. The construction and operation of the molecular still as it is commercially used at present compensates for these inequalities. The high vacuum in the region of 1 micron (0.001 mm mercury) pressure in an enclosed vessel eliminates the interference of molecules of dissolved and entrapped gases. This makes it possible to distill the long molecule of organic compounds without breaking them when they are exposed to moderate heat for a short time. The molecules of gas and of the organic substance are removed from the presence of the decomposing substance by means of the high-vacuum pump and are condensed in fractions according to their molecular weights. Included in the group of substances which can be distilled by this means are fats, waxes, resins, vitamins, sterols, and many others.

The molecular distilling apparatus is composed of a rotating disc heated by an electric resistance unit, with a beehive-shaped condenser over the face of the disc. This is enclosed in a tight vessel to which vacuum pumps are attached. The disc has a trough at the outer edge in which a syphon dips to remove the undistilled oil. The oil to be distilled drops onto the center of the rotating disc and rapidly traverses the surface and is retained by the trough. The portion of the substance having low molecular weight evaporates, is condensed on the condenser coils, and is collected in a receptacle. The higher molecular weight portion is caught in the trough at the edge and is syphoned off; it goes through the same process in another still operated at a slightly higher temperature.

The stills in use at present for distilling vitamin A from fish-liver oils contain a rotating disc, 32 inches in diameter and heated to a temperature of 266° F (130° C). These discs rotate at 3,000 to 5,000 rpm and are operated in a series containing 21 stills. These stills handle 500 to 1,000 pounds of fish-liver oil per hour.

There are five fractions in the distillation of fish-liver oils: (1) removal of gases; (2) products of rancidity and protein, which are rejected; (3) sterols, free fatty acids, esters, glyceride esters, natural preservatives, tocopherols (vitamin E), and their esters, which are given further distillation; (4) vitamin A and its esters, retained in storage and blending tanks; (5) glyceride fat residue, either sold for food or industrial purposes separately or combined with the residue from final vitamin E fraction, depending upon market conditions for nontocopherols.

The vitamin D fraction cannot be recovered economically to compete with manufacture of the synthetic product. Vitamin A is recovered as a concentrate ready for use as a dietary ingredient, and vitamin E is recovered for use after its final distillation.

"Solexol" Process for Concentrating Vitamin A. Passino (1949) has described a patented process for fractionating fish and fish-liver oils. This process is based upon the solubility of the oils in a hydrocarbon solvent, generally propane. The separation of the oil into fractions is controlled by regulating the temperature and pressure. The process has not been placed in any plant preparing vitamin A concentrates in the United States. All results reported at the present time have been obtained in the original plant set up for experimental purposes by the designers.

The apparatus is composed of several towers, the number depending upon the complexity of the oil or fat being fractionated. In the case of menhaden and sardine oils three towers are required, while cod-liver oil requires only two. In handling fish and fish-liver oils the first operation consists of neutralizing the oil with caustic and mixing it with liquid propane. The soap formed and the coloring matter are eliminated in the first tower. This portion averages approximately 2 per cent. The remaining portion passes into the second tower, where about 20 per cent is eliminated at the bottom of the tower by adjusting the temperature and pressure. The remainder of the solution then passes into the third tower, where conditions are again adjusted and all except approximately 10 per cent containing the vitamin A is eliminated. The final vitamin A concentrate is drawn off as an overhead product.

Fractionation of sardine and cod-liver oils proceeds through the process in similar steps. The percentages recovered from the different steps varies as does

the physical and chemical characteristics of the products eliminated in each step. The vitamin A concentrate is recovered in each instance as the final fraction. Tables 110–112 contain the results obtained.

TABLE 110. MENHADEN OIL FRACTIONATION.

Fraction	Crude	I	II	III	IV
Yield wt. per cent	—	2	20	68	10
Color, Gardner	11+	Black	10	4–	7
Color, Lovibond [1]	—	—	—	30Y–3.0R	—
Vitamin A potency unit per g	100	—	—	—	800
Unsaponifiable oil per cent	1.2	0.9	0.8	0.4	6.8
Free fatty acids per cent	1.3	0.5	0.4	0.3	11.8
Saponification No.	193	190	189	194	192
Iodine No.	175	260	225	165	90

[1] Lovibond readings are on a 5.25-inch cell.

TABLE 111. SARDINE OIL FRACTIONATION.

Fraction	Crude	I	II	III	IV
Yield wt. per cent	—	3.0	35.0	47.0	15.0
Color, Gardner	11	Black	8	4	5
Vitamin A potency unit per g	350	—	—	—	2100
Free fatty acids	1.0	0.5	0.4	0.3	6.0
Saponification No.	192	184	188	192	194
Iodine No.	185	250	240	160	110

TABLE 112. COD LIVER OIL FRACTIONATION.

Fraction	Crude	I	II	III
Yield wt. per cent	—	25	70.5	4.5
Vitamin A potency unit	2000	150	150	41,000
Free fatty acids per cent	0.8	0.07	0.04	0.5
Iodine No.	162	210	155	82
Saponification No.	186	182	188	185
Unsaponifiable oil	1.4	0.7	1.0	10.0
Color, Gardner	64	9–	1–	—

This process of fractionating oils is new and for this reason has not come into general use. It is understood that a plant in Capetown, South Africa, is installing this equipment for fractionating fish and fish-liver oils on a commercial scale.

Production of Vitamin A Oils in the United States

There are some indications that the production of high-vitamin A-bearing fish-liver oils has reached a peak of supply; unless new sources are found, there may be a serious shortage of this oil. In 1941 there was a production of approximately 1,125,000 gallons. After that peak was reached, production fell off each year until in 1948 the production was approximately 750,000 gallons. Opinion is divided as to the reasons for this gradual reduction. Most of the extractors are sufficiently concerned to investigate the possibilities of supplementing the domestic supply

TABLE 113. ANNUAL IMPORTATIONS OF FISH LIVERS AND VITAMIN-BEARING FISH LIVER OILS INTO THE UNITED STATES, 1934–1948.

Year	Cod, medicinal		Shark		Miscellaneous liver oils		Miscellaneous fish livers	
	Gallons	Value	Gallons	Value	Gallons	Value	Pounds	Value
1934	3,470,259	$2,190,985	—	—	[1] 1,624	$42,563	—	—
1935	4,607,093	2,975,298	—	—	[1] 1,662	23,587	—	—
1936	5,789,574	3,546,733	—	—	—	—	—	—
1937	5,915,964	3,866,971	—	—	—	—	2,473,962	$421,141
1938	5,228,637	3,326,496	—	—	—	—	4,931,580	658,057
1939	6,670,274	3,730,985	[2] 9,572	$6,773	[1] 2	50	6,254,873	1,717,945
1940	3,114,392	2,521,239	[2] 65,135	38,218	—	—	8,443,877	2,462,085
1941	1,695,841	2,945,877	[2] 367,887	587,374	101,467	314,393	4,943,666	1,221,841
1942	636,836	1,299,874	[2] 173,353	426,231	1,404	47,245	3,751,042	1,631,559
1943	1,804,467	3,504,293	144,674	502,239	261,346	1,469,803	4,004,088	2,201,129
1944	1,695,461	2,919,091	36	116	610,363	4,065,834	4,709,774	2,376,179
1945	1,768,015	2,891,707	82,512	155,018	521,773	5,285,461	4,150,946	1,544,341
1946	2,859,043	5,451,142	16,445	50,005	330,371	5,136,906	3,718,897	1,671,695
1947	1,520,247	3,195,469	4,614	20,898	142,689	4,282,919	2,926,120	1,653,834
1948	2,037,066	4,706,393	575,710	6,870,942	33,038	1,894,179	2,870,286	1,899,133

[1] Halibut-liver oil. [2] Shark-body oil and shark-liver oil.

Source: *Foreign Commerce and Navigation of the United States,* U. S. Department of Commerce.

by exploitation of the fisheries of several of the South and Central American countries.

International and U.S.P. Standards for Vitamin A

Rosenberg (1942) lists the interrelationship of the various vitamin A units used as follows:

"One I.U. (International Unit) = One U.S.P. unit; one I.U. = 0.6 microgram of pure beta-carotene, m.p. 184° C, optically inactive, dissolved in coconut oil with addition of hydroquinone; one I.U. = 1.5 to 2 Sherman units.

"One g of U.S.P. cod-liver oil must contain at least 600 U.S.P. units of vitamin A. (Since July 1, 1940, a minimum of 850 units per g is required.)

"One g of pure vitamin A contains 4,500,000 International Units.

"One Cod Liver Oil Unit (C.L.O. Unit)

= 125 gamma (1 gamma = 10^{-6} g) of beta-carotene
= 208 U.S.P. units
= 10 "Lovibond units"
= 50 Lovibond units (Wolff)
= 550 blue units (Moore)

"In British practice, one International Unit of vitamin A is in effect defined by

$$E^{1\%}_{1\,\text{cm}}\ 328\ \text{millimicrons} = 0.000625$$

which is equivalent to the use of 1600 as conversion factor for the physical measurement value. In the United States the conversion factor of 2000 is usually used instead of 1600."

Table 114. Annual Production of Vitamin-bearing Fish Liver Oils in the United States, 1934–1948.

Year	Species	Atlantic and Gulf Coasts [1]		Pacific Coast, including Alaska		Total	
		Gallons	Value	Gallons	Value	Gallons	Value
1934	Cod	94,312	$56,643	—	—	94,312	$56,643
	Miscellaneous [2]	2,526	100,872	6,073	$79,221	8,599	180,093
	Total	96,838	157,515	6,073	79,221	102,911	236,736
1935	Cod	215,479	227,019	—	—	215,479	227,019
	Miscellaneous [3]	11,605	539,687	71,773	2,799,147	83,378	3,338,834
	Total	227,084	766,706	71,733	2,799,147	298,857	3,565,853
1936	Cod	281,374	170,779	—	—	281,374	170,779
	Shark	—	—	2,860	1,010	2,860	1,010
	Miscellaneous [4]	26,526	1,099,266	40,640	1,625,600	67,166	2,724,866
	Total	307,900	1,270,045	43,500	1,626,610	351,400	2,869,655
1937	Cod	275,802	167,572	—	—	275,802	167,572
	Miscellaneous [5]	34,777	821,797	37,342	1,214,728	72,119	2,036,525
	Total	310,579	989,369	37,342	1,214,728	347,921	2,204,097
1938	Cod	261,556	164,986	—	—	261,556	164,986
	Shark	[6]	[6]	[6] 129,705	[6] 330,397	129,705	330,397
	Miscellaneous [7]	15,836	648,426	99,106	1,332,534	114,942	1,980,960
	Total	277,392	813,412	228,811	1,662,931	506,203	2,476,343
1939	Cod	318,069	196,296	—	—	318,069	196,296
	Shark [8]	[8]	[8]	[8] 135,467	[8] 845,876	135,467	845,876
	Miscellaneous [9]	19,382	828,375	205,057	2,601,141	224,439	3,429,516
	Total	337,451	1,024,671	340,524	3,447,017	677,975	4,471,688
1940	Cod	281,257	253,168	—	—	281,257	253,168
	Shark	28,018	44,780	213,084	1,087,790	241,102	1,132,570
	Tuna	9,544	642,828	217,009	2,188,963	226,553	2,831,791
	Miscellaneous [10]	7,765	295,374	33,944	575,250	41,709	870,624
	Total	326,584	1,236,150	464,037	3,852,003	790,621	5,088,153
1941	Cod	[11] 325,078	[11] 482,892	[11]	[11]	325,078	482,892
	Shark	41,478	1,170,665	566,411	8,030,983	607,889	9,201,648
	Tuna	7,258	548,990	158,804	1,365,160	166,062	1,914,150
	Miscellaneous [12]	17,005	1,121,975	117,208	2,150,923	134,213	3,272,898
	Total	390,819	3,324,522	842,423	11,547,066	1,233,242	14,871,588
1942	Cod	212,301	354,550	—	—	212,301	354,550
	Shark	66,172	557,119	613,123	6,563,664	679,295	7,120,783
	Tuna	616	25,550	43,780	376,989	44,396	402,539
	Other [13]	8,619	354,055	56,301	1,802,980	64,920	2,157,035
	Total	287,708	1,291,274	713,204	8,743,633	1,000,912	10,034,907
1943	Cod	133,222	189,363	—	—	133,222	189,363
	Shark	74,613	513,999	473,433	9,418,475	548,046	9,932,474
	Tuna [14]	[14]	[14]	26,823	1,305,146	26,823	1,305,146
	Miscellaneous [15]	16,030	49,976	127,733	3,365,011	143,763	3,414,987
	Total	223,865	753,338	627,989	14,088,632	851,854	14,841,970
1944	Cod	82,619	123,796	—	—	82,619	123,796
	Shark	85,489	614,869	711,368	9,004,496	796,857	9,619,365
	Tuna	703	20,430	39,102	1,428,025	39,805	1,448,455
	Miscellaneous [16]	1,638	45,471	56,004	1,983,292	57,642	2,028,763
	Total	170,449	804,566	806,474	12,415,813	976,923	13,220,379
1945	Cod	122,796	253,603	—	—	122,796	253,603
	Shark	98,545	429,917	448,234	6,092,992	546,779	6,522,909
	Tuna	[17]	[17]	[17] 51,399	[17] 1,576,922	51,399	1,576,922
	Miscellaneous [18]	21,407	452,775	61,907	2,395,998	83,314	2,848,773
	Total	242,748	1,136,295	561,540	10,065,912	804,288	11,202,207
1946	Cod	139,837	281,800	—	—	139,837	281,800
	Shark	91,820	554,830	546,628	7,100,291	638,448	7,655,121
	Tuna	[17]	[17]	[17] 42,751	[17] 1,465,066	42,751	1,465,066
	Miscellaneous [19]	2,217	82,307	72,631	4,133,355	74,848	4,216,562
	Total	233,874	919,837	662,010	12,698,712	895,884	13,618,549

TABLE 114. ANNUAL PRODUCTION OF VITAMIN-BEARING FISH LIVER OILS IN THE UNITED STATES, 1934–1948. (*Continued*)

Year	Species	Atlantic and Gulf Coasts [1]		Pacific Coast, including Alaska		Total	
		Gallons	Value	Gallons	Value	Gallons	Value
1947	Cod	260,377	556,546	—	—	260,377	556,546
	Shark	60,927	348,549	430,013	6,285,501	490,940	6,634,050
	Tuna	[17]	[17]	[17] 43,305	[17] 1,373,609	43,305	1,373,609
	Miscellaneous [20]	2,165	78,065	35,723	3,001,198	37,888	3,079,263
	Total	323,469	983,160	509,041	10,660,308	832,510	11,643,468
1948	Cod	214,127	583,426	—	—	214,127	583,426
	Shark	[8]	[8]	[8] 434,010	[8] 6,315,232	434,010	6,315,232
	Tuna	[17]	[17]	[17] 25,459	[17] 1,094,241	25,459	1,094,241
	Miscellaneous [21]	1,995	111,286	64,546	4,403,467	66,541	4,514,753
	Total	216,122	694,712	524,015	11,812,940	740,137	12,507,652

[1] Includes the production of burbot-liver oil in Minnesota and Wisconsin.
[2] Includes halibut- and burbot-liver oils from the Atlantic Coast and miscellaneous liver oils from the Pacific Coast (from original data not segregated in the annual summary).
[3] Partly estimated.
[4] Includes burbot-, halibut-, sablefish-, swordfish-, tuna-, "lingcod-," and totuava-liver oils.
[5] Includes burbot-, halibut-, sablefish-, swordfish-, tuna-, shark-, and miscellaneous liver oils.
[6] Production from Massachusetts and Florida included in Pacific Coast data.
[7] Includes burbot-, halibut-, sablefish-, swordfish-, tuna-, and miscellaneous liver oils. A small quantity of halibut viscera oil has been included with the Pacific Coast production of miscellaneous liver oils.
[8] Shark-liver oil production in Florida included under Pacific Coast.
[9] Includes burbot-, flounder-, halibut-, "lingcod-," mackerel-, sablefish-, swordfish-, tuna-, and miscellaneous liver oils.
[10] Includes burbot-, halibut-, mackerel-, sablefish-, swordfish-, and miscellaneous liver oils on the Atlantic Coast, and flounder-, halibut-, sablefish-, and miscellaneous liver oils on the Pacific Coast.
[11] A small quantity of cod-liver oil produced in Washington has been included with the production of cod-liver oil on the Atlantic Coast.
[12] Includes burbot-, halibut-, sablefish-, mackerel-, swordfish-, and miscellaneous liver oils on the Atlantic Coast, and flounder-, halibut-, sablefish-, mackerel-, and miscellaneous liver oils on the Pacific Coast.
[13] Includes the production of burbot-, swordfish-, and mixed-liver oils on the Atlantic Coast and mixed-liver oils on the Pacific Coast.
[14] The production of tuna-liver oil in Massachusetts has been included with the production of that item on the Pacific Coast.
[15] Includes burbot-, swordfish-, mixed-liver, and industrial cod-liver oils on the Atlantic Coast, and flounder-, halibut-, sablefish-, and mixed-liver oils from the Pacific Coast.
[16] Includes burbot-, swordfish-, halibut-, and mixed-liver oils on the Atlantic Coast, and flounder-, halibut-, "lingcod-," rock cod-, rockfish-, sablefish-, and mixed-liver oils on the Pacific Coast.
[17] A small quantity of tuna-liver oil produced on the Atlantic Coast has been included with the production on the Pacific Coast.
[18] Includes the production of burbot-, swordfish-, halibut-, and mixed-liver oil on the Atlantic Coast, and flounder-, halibut-, "lingcod-," rockfish-, sablefish-, and mixed-liver and viscera oils on the Pacific Coast.
[19] Includes the production of burbot-, halibut-, sea bass-, swordfish-, and mixed-liver oils on the East Coast, and "lingcod-," halibut-, rockfish-, sablefish-, and mixed-liver and viscera oils on the West Coast.
[20] Includes the production of burbot-, halibut-, swordfish-, and mixed-liver oils on the East Coast, and halibut-, "lingcod-," rockfish-, sablefish-, skate-, sole-, and mixed-liver and viscera oils on the West Coast.
[21] Includes the production of burbot-, halibut-, rockfish-, and swordfish-liver oils on the East Coast, and halibut-, "lingcod-," sablefish-, mixed-liver oils and viscera oils on the West Coast.

REFERENCES

Anon., "Tubes, Capsules, and Enclosures," *Can. Chem. and Process Ind.*, **27**, No. 5, 248–249 (1943).

Anon., "Atlantic Coast Dogfish Livers," *Canadian Fisherman*, **3**, No. 4, 6 (1944).

Anon., "Guide to Commercial Shark Fishing in the Caribbean Area," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **135**, 33 (1945).

Anon., "Vitamin Production in Argentina," *Norsk Medicinal Union*, Bergen, Norway (1946).

Bailey, B. E., "Stability During Household Storage of Vitamin A," Fishery Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **54**, 15–17 (1943).

Bailey, B. E., "Preparation of Vitamin A Oils from Dogfish Livers," Fishery Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **50**, 10–12 (1941).

Baird, F. D., Ringrose, A. T., and Macmillan, M. J., "Stability of Vitamin A in Mixed Feeds," *Poultry Sci.*, **18**, 441–448 (1939).

Baxter, J. G., and Robeson, C. D., "Crystalline Vitamin A Palmitate and Vitamin A Alcohol," *Science*, **92**, 202 (1940).

Bethke, R. M., Record, P. R., and Wilder, O. H. M., "Stability of Carotene and Vitamin A in Mixed Rations," *Poultry Sci.*, **18,** 179–187 (1939).

Brocklesby, H. N., and Green, K., "Methods for Production of Oils from Livers of Low Oil Content," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **22,** 18 (1934).

Brocklesby, H. N., and Green, K., "The Preservation of Halibut Livers and Intestines," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **36,** 7–10 (1938).

Butler, C., "The Fish-Liver Oil Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet,* 233 (1948).

Buxton, L. O., "Effect of Carbon Treatment on Fish-Liver Oils, Vitamin A Destruction and Peroxide Formation," *Ind. Eng. Chem.*, **34,** 1486–1489 (1942).

Carr, F. H., and Price, E. A., "Color Reactions Attributed to Vitamin A," *Biochem. J.*, **26,** 498 (1926).

Crowther, H. E., "Oil Separation Method for Vitaminiferous Protein Material and the Like," U. S. Pat. 2,413,692 (1947).

Embree, N. D., "Report of the Vitamin Committee 1945–46," *Oil and Soap,* **23,** No. 9, 275–276 (1946).

Ewe, G. E., "Stability of Cod-Liver Oil under Commercial Distribution Conditions," *J. Am. Pharm. Assoc.*, **22,** 1085–1086 (1934).

Golumbic, C., and Mattill, H. A., "Antioxidant Properties of Gallic Acid and Allied Compounds," *Oil and Soap,* **19,** 144–145 (1942).

Guttman, A., "The Value of Cod Liver Residue," Fisheries Research Board Canada, *Prog. Repts., Atlantic Station.* **49,** 5 (1950).

Harrison, R. W., and Hamm, W. S., "Extraction of Vitamin A from Dogfish Livers," *Pacific Fisherman,* **39,** No. 9, 37–39 (1941).

Hempel, H., "Method of Treating Fish Livers," U. S. Pat. 2,156, 985 (1939).

Hickman, K. C. D., "Adventures in Vacuum Chemistry," *American Scientist,* **33,** 205–231 (1944).

Holder, R. C., and Ford, S. K., "Stability of Vitamin A in Mixed Feeds," *Poultry Sci.*, **18,** 345–349 (1939).

Holmes, H. N., Corbet, R. E., and Hartzler, E. R., "Lecithin and Hydroquinone as Antioxidants for Vitamin A," *Ind. Eng. Chem.*, **28,** 133–135 (1936).

Holmes, A. D., and Pigott, M. C., "Effect of Light on Vitamin A Content of Cod-Liver Oil," *Boston Med. Surg. J.*, **195,** 263–265 (1926).

Holmes, A. D., and Pigott, M. G., "Comparative Stability of Vitamin A in Cod Liver Oil," *J. Amer. Pharm. Assoc.*, **31,** 521–523 (1942).

Hopkinson, L. T., "Method of Producing Oil from Oil-Containing Material," U. S. Pat. 2,107,245 (1938).

Kuhn, R., and Morris, C. J. O. R., "Synthesis of Vitamin A," U. S. Pat. 2,263,375 (1941).

Labrie, H., and Fougere, H., "New Cod-Liver Oil Extractor," Fisheries Research Board Canada, *Prog. Repts., Gaspé Exptl. Sta.*, **21,** 6–8 (1937).

Lundberg, W. O., Halverson, H. O., and Burr, G. O., "The Antioxidant Properties of Nordihydroguaiaretic Acid," *Oil and Soap,* **21,** 31–35 (1945).

Mattill, H. A., "Oxidative Destruction of Vitamins A and E, and Protective Action of Certain Vegetable Oils," *J. Am. Med. Assoc.*, **89,** 1505–1508 (1927).

Milas, N. A., "Synthesis of Vitamin A," U. S. Pat. 2,382,085 (1942).

Miller, W., and Jonkovsky, V., "Effect of Manganese Sulfate on the Stability of Vitamins A and D of Cod Liver Oil When Stored in Mixed Feeds," *Poultry Sci.*, **21,** 200–202 (1942).

Nielsen, C., "Method of Extracting Liver Oil," U. S. Pat. 2,078,404 (1937).

Oliver, T. R., "Molecular Distillation, a New Path to Separation of Chemicals," *Chem. Met. Eng.*, **51,** 100–104 (1944).

Passino, H. J., "The Solexal Process," *Ind. Eng. Chem.*, **41,** 280–287 (1949).

Pugsley, L. I., "Variations in Vitamin A Content of Liver Oils in the Grayfish," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* 33, 3–5 (1937).

Rapson, W. S., and Schwaryz, H. M., "South African Fish Products. III. The Stonebass," *J. Soc. Chem. Ind.,* **63,** 18–21 (1944).

Robinson, F. A., "Stability of Vitamin A and D to Oxidation," *Biochem. J.,* **32,** 807–814 (1938).

Rosenberg, H. R., "Chemistry and Physiology of the Vitamins," New York, Interscience Publishers, Inc., 1942.

Robeson, C. D., and Baxter, J. G., "Alpha-Tocopherol, a Natural Antioxidant in Fish-Liver Oil," *J. Am. Chem. Soc.,* **65,** 940–943 (1943).

Sanborn, H. N., "Lethal Effect of Chemicals on Fresh Fish," *Food Packer,* **26,** No. 8, 40–41 (1946).

Sanford, F. B., and Jones, G. I., "Liquid Gold," *International Fisherman and Allied Worker,* **6,** No. 4, 5 (1946).

Simons, E. J., Buxton, L. O., and Coleman, H. B., "Relation of Peroxide Formation to Destruction of Vitamin A in Fish-Liver Oils," *Ind. Eng. Chem.,* **32,** 706–708 (1940).

Smith, E. L., "Action of Peroxides on Vitamin A," *Biochem. J.,* **33,** 201–206 (1939).

Walford, L. A., "Observations on the Shark Fishery in the Central Part of the Gulf of California with Records of Vitamin Potency of Liver Oils and with Keys to Identification of Commercially Important Sharks," U. S. Fish and Wildlife Service, *Fishery Market News,* **6,** No. 6, 3 (1944).

Wentworth, H. A., "Method of Preparing Fish-Liver Oils," U. S. Pat. 2,134,163 (1938).

Wood, B. A., and Ferguson, E. J., "Commercial Production of Fish-Liver Oils," *J. Council Sci. and Ind. Research,* **14,** No. 4, 311–314 (1941).

Young, F. H., and Robinson, H. D., "Process of Obtaining Vitamin-Containing Oils," U. S. Pat. 2,136,481 (1932).

CHAPTER 24

Fish Glue and Isinglass

Manufacture of Fish Glue

Importance and Location of Industry

The fish-glue industry is one of the minor by-products industries. In 1948 five factories in the United States produced a total of 215,400 gallons. These factories are located in Gloucester and Boston, Massachusetts, in Maine, and in California. Small amounts of fish glue are manufactured in Canada. In England it is made in some fish-scrap factories from the water in which the fish have been cooked. Considerable quantities are prepared in Norway and Japan. The great obstacle confronting the industry is the difficulty of obtaining a regular supply of suitable stock in sufficient quantities.

Chemistry of Fish-Glue Manufacture

The conversion of animal hides and bones into gelatin and glue has been the subject of much research; but little has been published concerning the preparation of fish gelatin and glue. The hydrolysis of fish sounds or air bladders most nearly resembles the manufacture of hide glue, for the tissue dissolves when heated with water; if the resultant solution is evaporated and cooled, a gel is formed which is a gelatin of high purity. Upon hydrolysis most other portions of fish yield glue solutions which do not gel at ordinary temperatures; these are called liquid glues.

Comparatively little is known of the composition of fish skin, scales, and bones. However, it has been found that fish skin and bones contain quantities of collagen and other proteins resembling collagen. The scales of fish also contain much ichthylepidin. Upon careful hydrolysis with steam or boiling water the collagen and related proteins yield gelatin and various proteoses. The percentage of true gelatin formed in the manufacture of fish glue is much smaller and that of proteoses is much higher than in the manufacture of hide or bone glue. Since the proteoses are soluble in cold water, whereas gelatin is not, fish glues are cold water-soluble; but hide glues merely swell in cold water and do not dissolve until the water is heated.

Source of Raw Materials

Practically all the fish glue now manufactured is made from the waste products of the cod, haddock, cusk, hake, and pollock fisheries. These fish are the so-called "ground" fish, which are caught chiefly in otter-trawl nets on the banks. Some other species are sometimes used in the manufacture of glue—indeed any fish may be so used—but for several practical and economic reasons other fish are seldom involved. The quality of glue prepared from these ground fish is higher

and the yield greater than in glues made from most other fish. Many species of fish have thin skin and small bones, and therefore yield such small quantities of glue that it is not economical to use them; examples of this type of fish are herring, mackerel, and menhaden. Moreover, since these fish contain large quantities of fat, a special procedure must be followed to remove it during the glue-making process. Many fish which would otherwise be used are not caught in large enough quantities in any one locality, and consequently the supply of fish waste at any particular point is not sufficient to justify the establishment of a glue factory. Other fish are caught only for short seasons; as a result, the glue factories would be idle most of the year.

The ground-fish waste ordinarily is divided into three general classes: (1) fish heads; (2) waste from salted fish (strictly speaking salt-fish trimmings and bones, but usually considered trimmings and bones from salted cod, cusk, hake, pollock, and haddock, and haddock and pollock skins); (3) skin stock (usually considered only skin from salted cod and cusk). The fish heads are fresh stock and are obtained from the wharves where the ground fish are cleaned before salting or marketing. With the exception of the exported salt fish most of the dried salted fish are trimmed and skinned before being packed for shipment. Most of them are also boned. These skins, trimmings, and bones constitute waste and skin-glue stock. Cod and cusk skins are thicker and furnish larger amounts of a better grade of glue than pollock and haddock skins; cod and cusk heads are also more valuable as glue stock than pollock and haddock heads. Because of this the larger fish-glue factories pay higher prices for cod and cusk skins and heads than for similar haddock and pollock stock; therefore, many of the larger fish salters keep these two classes of glue stock separate.

Methods of Manufacture

Skin Glue. The glue stock, regardless of whether it is obtained from fresh or salted fish, must be freed from salt (freshened) before being made into glue. It is ordinarily agitated in running water until a chloride analysis of the wash water indicates that practically all the salt has been washed out. In the larger factories this is accomplished by placing the stock in a circular tank about 30 feet in diameter and 5 feet deep, covering it with water, and rolling it with a heavy wooden truncated-cone-shaped roller, which revolves as it travels around the tank. These washers are efficient, for the roller squeezes out a portion of the water in the stock as it rolls over it; the stock then takes up more water, which is squeezed out on the next revolution of the roller. Unfortunately, the stock tends to collect at the center of the washers and from time to time it must be pitched from the center toward the outside. A small stream of water is run through the washers continually, and at intervals all the water is withdrawn and the tanks are refilled with fresh water. The fish skin and waste stock, being waste products of the salt-fish industry, contain a much greater percentage of salt than the fish heads; hence more care must be used in freshening them than in freshening fish-head stock.

Washing the stock requires at least 12 hours and often much longer. The usual practice is to weigh the stock as it is received from the fish wharves and dump it into the washers. After distributing a weighed quantity uniformly in a washer the stock is covered with water and the agitator (roller) is started. Washing is usually

started during the afternoon and is continued until the following morning, when the percentage of chlorides in the wash water is determined; if the analysis indicates that little salt remains in the stock, the washing is discontinued and the water drained off.

The heavy roller disintegrates a portion of the stock, which passes through the screen with the wash water. To prevent this loss in some of the larger factories the wash water is run into large settling tanks through which it slowly passes. This permits the major portion of suspended matter to settle. The settlings are usually added to the chum or residue from the cooking, which is then pressed, dried and sold as poultry food.

The freshened skin stock is pitched into the cookers which are usually situated adjacent to the washers. The usual type of cooker consists of a steam-jacketed, false-bottomed, rectangular galvanized iron tank. These cookers are often about 12 feet long, 3 feet wide, and 5 feet deep. A layer of excelsior is thrown on the false bottoms when the cookers are prepared for use, and the stock is thrown in. A preservative is added at this stage to prevent decomposition of the glue liquors during storage before evaporation. A small amount of acetic acid or other moderately strong acid is added to the stock; this acid acts as a catalytic agent and hastens the hydrolysis of the stock into glue. Moreover, it reduces the slime in the chum so that it may be more readily pressed and more easily dried. The stock is covered with water; the steam is turned into the outer jacket and the cooking is continued for 6 to 10 hours. Then the glue liquor is drawn off and pumped to tanks and thence to the evaporators. The partially exhausted stock is again covered with water and cooked for a somewhat shorter period. Usually the skin stock is cooked only twice; the residue from the second cooking is commonly added to the freshened waste stock. Thus no glue is lost.

The glue liquor is usually filtered through a mat of excelsior as it passes to the pump on its way to the tanks situated above the evaporator; as the liquor flows into the evaporator, it is often strained through muslin. These filtrations remove most of the suspended material.

Many types of evaporators are in commercial use. Vacuum evaporators are the most efficient, but are not commonly used because of the great tendency of fish-glue liquor to foam. Open pans heated with steam coils are used in many of the smaller fish-glue factories. One popular type of evaporator consist of a large copper coil, about 6 feet in diameter, which revolves in a shallow, copper-lined wooden tank. Steam passing through the coil causes the glue liquor to evaporate rapidly on the surface of the coil while it is carried out of the body of the liquor as the coil revolves.

Evaporation is continued until the glue reaches the proper viscosity, or "body," as it is commonly termed. This stage is determined by comparing the viscosity of a sample of the glue with that of a standard sample, either in viscosity tubes or in a viscosimeter of the Stormer type, which is most satisfactory for the purpose. When the tests indicate that the proper viscosity has been reached, the additional preservatives and essential oils are added and the glue is drawn off ready to be tubed, bottled, or canned.

Photoengraving Glue. Only the very best grades of fish-skin glue are satisfactory photoengraving glues. The procedure followed in their manufacture does not differ from that outlined above for regular skin glue. Smaller amounts of essential

oils and preservatives are used for its preservation. Only the first two runs of the best quality of fish-skin glue stock are taken. Special care is used to prevent the admixture of stock or glue containing any considerable amount of grease as grease and oil cause spots on the photoengraved halftone plates. Moreover, a uniform admixture of the essential oil in the glue must be insured; improper mixing causes some of the bottles of glue to be of poor quality because of an excess of oil. Photoengraving glue also may be clarified either by a special settling process or filtration before it is bottled. Even with the greatest care in manufacture each batch of glue must be tested very carefully to determine whether or not it is suitable for use in delicate work.

Waste Glue. Waste glue, as previously explained, is prepared from salted ground-fish trimmings and bones and from haddock, hake, and pollock skins. This stock is washed and converted into glue in practically the same manner as that used in the preparation of fish-skin glue. The type of washer already described is used. Cooking is accomplished in the galvanized iron-jacketed cookers, although direct-steam cookers are occasionally used. More acid is used for the conversion; the amount depends somewhat upon the proportion of the bones in the stock—the more bones the more acid required; but the usual amount is about 1 gallon of glacial acetic acid per ton of glue stock. Two and sometimes three cookings are made; the first is usually of about 10 hours' duration, less time being required for subsequent cookings. Much higher percentages of preservatives are usually added to the stock before cooking. The filtration and evaporation of glue liquor are effected in the same manner as previously described for skin-glue liquor. The total amount of preservatives in the finished glue is often in excess of 1 per cent, although this varies with the nature of the preservatives. Phenol, cresol, beta-naphthol, boric acid, and cresylic acid are commonly used. Larger amounts of essential oils are usually added to waste glues than to fish-skin glues. The essential oils in common use include cassia, wintergreen, sassafras, artificial sassafras, and peppermint.

Waste glues are often sold expressly for wood-joining work; therefore, small amounts of zinc oxide are often added to partially opaque the glue. If transparent liquid glues are used for joining work, the dried joint is dark and very noticeable.

Fish-Head Glue. The methods used to convert fish heads into glue are not as well known as those for fish skin and waste stock, although, needless to say, they are much the same. Washing is done in the same way, although larger washers are commonly used, as more fish-head stock must be handled to obtain the same quantity of glue. Two types of cookers are in general use: one resembles that used for the conversion of skin and waste stock, except that it is much larger—about 12 feet long, 8 feet wide, and 5 feet deep; the other is a large, pear-shaped steel boiler. Sodium bisulfite or sulfurous acid is often added to the stock just before cooking is commenced; these agents effect considerable bleaching. Because of the relatively large proportion of bone in fish heads much larger percentages of acid are required. Two gallons of acetic acid per ton of stock is the usual proportion. If much less acid is used, the residue is difficult to press and dry.

Fish-head glue liquors are evaporated according to the procedure described for skin and waste glue liquors. The same antiseptics are used to preserve the finished glue; larger amounts of essential oils are usually added to fish-head glues to mask their disagreeable odor.

Since fish-head glues are widely used for joining wood, sufficient zinc oxide is usually incorporated to make them nearly opaque.

Yield of Glue from Stock

The yield of liquid glue obtained from cod and cusk skin is usually between 60 and 80 gallons per ton of stock. Hake, haddock, and pollock skins yield much less glue; the usual amount obtained is from 35 to 45 gallons per ton. Trimmings and bones (waste) from salted ground fish yield about 25 gallons of liquid glue per ton although as much as 30 gallons are occasionally obtained. The best yields of liquid glue obtained from fish heads are 15 to 18 gallons per ton of stock although the yield often falls as low as 12 gallons per ton.

Composition and Properties of Fish Glue

Composition

Fish glue of the usual viscosity contains from 50 to 55 per cent of dry glue and weighs from 9.5 to 10 pounds per gallon. In addition to glue it contains about 1 per cent preservatives, 0.2 to 0.4 per cent essential oils, and usually a small proportion of zinc oxide or some other white pigment; from 0.5 to 1.0 per cent of ethyl or methyl alcohol is often found.

Comparatively few analyses of the dry matter of fish glue have been made. Dry-fish skin and fish-waste glues have about 1 per cent ash; the amount of ash in fish-head glues varies, depending on the methods of manufacture and the amount of pigment or other inorganic materials added during manufacture. A sample of the ash of fish-skin glue analyzed by Tressler (1921) had the following composition:

Analysis of Ash

		Per Cent
Ash in dry matter	0.96	
Silica (SiO_2)		12.7
Calcium oxide (CaO)		10.5
Magnesia (MgO)		trace
Potash and soda (K_2O and Na_2O)		13.9
Sulfur trioxide (SO_3)		34.0
Phosphorus pentoxide (P_2O_5)		24.9
Chlorine (Cl)		3.2
Ferric oxide (Fe_2O_3)		trace
		99.2

Bogue (1920) carried out the most detailed exact analyses of the dry matter of fish glue of any that have been published, but unfortunately he does not state which kind of fish glue he analyzed. His results are given in the table on page 259.

Fish glue owes its property of complete solubility in water at ordinary temperatures (e.g., 68° F [20° C]) to its low gelatin content, as is shown by its relatively low percentage of protein nitrogen and its high proteose and peptone nitrogen content; the latter two are completely soluble in cold water.

TABLE 115. NITROGENOUS CONSTITUENTS OF GLUE.

	Per Cent
Protein N	33.4
Proteose N	42.3
Peptone N	21.9
Amino Acid N	2.4
	100.0

Purified [1] *Protein Analysis*

	Per Cent
Ammonia N	5.15
Melanin N	1.12
Cystine N	trace
Arginine N	13.80
Histidine N	2.04
Lysine N	8.58
Amino N in filtrate	60.20
Nonamino N in filtrate	9.66
	100.55

[1] Precipitated with 95 per cent alcohol, redissolved and reprecipitated 4 times.

Source: Bogue, R. H., "Properties and Constitution of Glues and Gelatin, IV," *Chem. Met. Eng.*, 23, 154–158 (1920).

Bogue has compared the composition of the amino acid groups of fish glue with that of bone and hide glues. He concludes:

"This glue (fish glue) shows higher ammonia, melanin, and amino nitrogen of the filtrate, and lower nonamino nitrogen of the filtrate than any other glue, but more nearly corresponds to the low-grade bone glues than to the hide series. Only in its high amino nitrogen of the filtrate does it resemble the latter. The very low nonamino nitrogen of the filtrate in the case of both the fish products indicates a fundamental distinction from animal glues."

Examination of Liquid Glue

Many liquid glues are manufactured from materials other than fish stock. Their quality varies greatly; and unfortunately not all the fish glues marketed are of the highest quality. However, this is also the case with hard glues as both bone and hide glues vary widely in properties. Methods of determining the quality of hard glues have been known for many years, but few buyers of liquid glue are able to determine the quality of their glue by analytical methods. For this reason methods of examination of fish and other liquid glues will be outlined in some detail.

The properties desired in a liquid glue depend upon the use to which it is put. Glue suitable for joining work is considered the best for general use. Special work, such as labeling, requires special glue; since each type of such work calls for a different quality of glue, it is obviously impossible to consider all of them here. Liquid glues adapted for joining work will therefore be the only ones discussed.

Liquid glues used for joining work should possess high tensile and shearing strength under all ordinary weather conditions. Properties controlling strength include hygroscopicity, chemical composition, viscosity and flow at low temperatures. If a liquid glue is to be used in cool rooms, its gel point must be relatively low. The color and opacity of the liquid glue affect the appearance of the joint. Clear glues appear darker on wood than opaque glues, provided the opacity is not caused by dark-colored pigments (i.e., blues, blacks, or browns).

Gel Point. To determine the gel point of a liquid glue accurately it should be cooled very slowly and the temperature at which flow ceases should be noted. A simple rapid method, accurate within half a degree, is to cool rapidly a sample of liquid glue in a test tube immersed in cold water, noting the gelling temperature and then melting the gel in warmer water. The average of the melting point of the gel and the observed gel point is a close approximation of the true gel point.

Viscosity. This property is easily determined in a Stormer viscosimeter if a 500-gram weight is substituted for the 100-gram capsule with which the standard model of this machine is ordinarily equipped. Viscosity determinations are of the most value when the viscosities of a given glue are determined at a series of temperatures and plotted against the temperature on coordinate paper. The curve gives much information as to the flow of the glue at various temperatures, the concentration of the glue solution, and the presence of gel-inhibiting substances. Moreover, the gel point is accurately indicated by the point at which the viscosity reaches infinity.

Moisture. The procedure for determining the percentage of moisture should be uniform in all cases; heating for 5 hours at the boiling point of water will give satisfactory results.

Speed of Set. When liquid glue is first applied to a wood joint, the wood absorbs a certain amount of water; in a short time, usually a minute or two, the liquid "sets" or gels and the joint attains some strength. This gelling is termed "setting" because of absorption of moisture by the object to which the glue is applied. The time elapsed between the application of the glue and the gelling or preliminary drying of the liquid glue is known as the "speed of set." No accurate methods have been proposed for determining this property. A rough approximation of the relative speed of setting of various liquid glues may be gained by brushing a thin layer on paper and noting the number of seconds elapsing before a skin forms on the surface of the glue. Such results are of no value unless they are compared with similar data obtained with glues of known setting properties.

Ash Content and Composition of Ash. It is very difficult to obtain glue ash, free from carbon, without volatilizing some chlorides and other easily volatilized inorganic substances. For this reason, the simple ignition of a weighed sample of glue does not give a true sample of ash. The samples used in the determination of solid matter may also be taken for the ash determinations. They should be moistened with standard calcium acetate solution and ignited according to the method adopted by the Association of Official Agricultural Chemists.

Aside from indicating the total amount of inorganic materials in the glue the ash content is of little value as an index of the quality. Examination of the ash is of much more value to the chemist. The presence of large percentages of chlorides indicates that the glue is hygroscopic. Most manufacturers of fish glues consider this the best index of the hygroscopicity of a glue; therefore, a chloride

determination is made on each batch of glue manufactured. The liquid glues are then graded according to the percentage of chlorides they contain. The best fish glues should not contain more than 0.02 per cent of chlorine as chloride.

Drying Properties. The relative rate of drying may be judged fairly by comparing the drying qualities of a sample of liquid glue when spread on a glass plate with those of a standard sample. The time required for a layer 0.2 cm in depth to dry, at a given humidity and temperature (e.g., 77° F [25° C]) and 70 per cent humidity, is noted and compared with the standard. The best grades of liquid glues dry to transparent, glossy films which are strong and brittle. If the dried film is easily powdered, the glue is of little value for most purposes.

Hygroscopic Properties. If the completely dried film of glue is placed in a constant-temperature, constant-humidity room, or in a humidor over a sulfuric acid solution, it absorbs some moisture. The gain in weight is an index of its hygroscopic properties. The absorption of moisture softens the glue film to a greater or less degree. If the dried films are placed over 80 per cent sulfuric acid at 77° F (25° C), those which become sticky and of the consistency of molasses are very hygroscopic and are of little value for joining work; if the film becomes flexible, the glue possesses slight hygroscopic properties.

Joint Strength. In the manner in which strength tests are ordinarily carried out on glues, they are of little value in grading the glues. Even accurate experimenters are unable to check their results closely. The weather conditions—temperature and humidity—have an important influence on the strength of all glues (hide, bone, fish, etc.). To obtain uniform results testing of the strength of glues must be carried out in constant-temperature, constant-humidity rooms. Fair results are obtained by drying the joints in a humidor at 77° F (25° C) over 90 per cent sulfuric acid. Three different strength tests are used in determining the joint strength of glues: shearing, tensile, and breaking. Of these only the shearing strength test has been generally recognized as a standard method. The procedure recommended by the U. S. Forest Products Laboratory is as follows:

Well-seasoned hard maple wood is sawed into two pieces, 12 by 2.5 by 1 inches. The contact surfaces should be planed just before the glue is applied. The glue is spread on both of the contact surfaces; then the blocks are allowed to stand to permit the glue to soak in for at least 15 hours, after which they are put in a rack and allowed to stand from 6 to 9 additional days. Each of the joints is sawed into four smaller joints. The blocks are broken apart by bringing a shearing strain to bear on the layer of glue between the two wooden halves of the joint in an Olsen Universal Testing Machine.

This method, when carried out under uniform conditions of temperature and humidity, gives admirable results with the weaker glues. As the stronger glues pull a larger or smaller area of the wood out, the test may not indicate the full shearing strength. For such glues the tensile- and breaking-strength tests give more uniform results.

Color. The color of liquid glues is most easily determined by clarifying the liquid glue with egg albumen and then matching the color with the glasses in a Lovibond Tintometer. Very light-colored glues are required for use on light woods. Darker glues may be used on dark woods without danger of making a conspicuous joint. Light-colored glues have a more pleasing appearance and therefore command a higher price.

Permanence. Another point of first importance in the consideration of the value of any liquid glue is its permanence. Not only must it retain its adhesive power indefinitely, but it must retain its original appearance (i.e., no coagulation, precipitation, or discoloration should appear after storage for long periods of time. The glue must, therefore, be preserved to prevent bacterial and mold growth, and it must not contain any suspended matter that will settle out on standing. The glue should be neutral to litmus, but slightly acid to phenolphthalein. One of the best tests that may be applied to a liquid glue to determine its permanence is storage at a slightly elevated temperature (98.6° F [37° C]). If liquid glue remains free from bacterial decomposition and other changes during a month's storage at this temperature, it is likely that it will keep indefinitely at ordinary room temperatures, provided it is properly preserved to prevent mold growth.

Interpretation of Analytical Results

If a liquid glue is to be used for joining work, the properties of prime importance are permanence, adhesiveness or strength, and hygroscopicity. If the glue is lacking in any one of these, it is of no value for use in joining wood. Other properties such as gel point, viscosity, color, and odor are of minor importance in most cases. Where the glue is to be used for special work, such as joining glass, other properties, for instance color and elasticity, become of importance.

In buying glue, viscosity, moisture content, and speed of set should be taken into consideration, for these properties determine the relative cost of liquid glues. Obviously, more glue of a low viscosity and high moisture content must be applied to joints than glue of high viscosity and low moisture content. If the liquid glue sets too quickly after it is applied, it will be impossible to spread uniformly; therefore, more glue must be applied in making the joint than would be the case if a slower setting glue were used.

By-products

The residue left in the cookers after the final cooking and draining contains a considerable quantity of glue liquor. This residue is placed in canvas bags in a hydraulic press and pressed; this accomplishes the dual purpose of recovering the glue liquor and of partially drying the chum. The recovered glue liquor is added to the main bulk of the liquor and evaporated. The residue in the hydraulic press is dried further, either by direct or indirect heat in a long, revolving cylindrical drier, and is then sold either as feed or as a fertilizer. At one time a large proportion of the dried chum was used for the preparation of fertilizer, but the demand for use as a poultry feed grew rapidly and now nearly the entire production is sold to poultrymen. The dried chum is an excellent poultry feed as it contains about 50 per cent protein in an easily digestible form; fish head and waste chum contain a high percentage of calcium phosphate. The latter constituent supplies calcium for the egg shell and phosphorus for the yolk.

Chum produced from "skins" contains (water-free basis) on the average 12.2 per cent nitrogen, calcium and magnesium phosphates 25.5 per cent; from "waste," 11.1 per cent nitrogen, calcium and magnesium phosphates 30.0 per cent; and from "fish heads," 10.0 per cent nitrogen, calcium and magnesium phosphates 36.6 per cent. The average composition of the mixed chum prepared for chicken feed is as follows:

	Per Cent
Moisture	12.0
Protein (Nitrogen × 6.25)	53.0
Calcium and magnesium phosphates	27.0
Fat	1.5
Salt	1.5
Crude fiber	0.8
Other ash constituents	4.2
	100.0

Many have claimed that the feeding of fish meal imparts a fishy flavor to animal products. This assumption is not well founded, as has been pointed out previously.

Uses

Fish glue is widely used for a large variety of purposes. It is the only glue manufactured that needs no further preparation for all general uses. Many ready-to-use glues are prepared from starch and dextrin, but these are limited to special purposes, such as labeling and box-making. The best grade of fish-skin glue is the only satisfactory glue for producing half-tone plates for photoengraving work. It is also used to some extent in the production of zinc line plates.

Fish glues are used largely where flexible glues are desired (e.g., in the manufacture of court plaster, labels, and stamps, and in bookbinding. Liquid fish glue is also almost universally used where small amounts of a strong, ready-to-use adhesive are required, as for small repair jobs about the house, for shoe-repairing, and for general repair work. Fish glue is blended with hide glue in the manufacture of belt cement for leather belts. Large quantities of the cheaper grades of fish glue are used in various sizing operations because it stiffens materials, yet is somewhat flexible. Some fish glue is used in the chipping of glass in the production of translucent glass. Large quantities of this glue are used by furniture makers, box makers, and other manufacturers for general joining work.

Fish Isinglass and the Isinglass Industry

Location

Russian isinglass prepared from sturgeon sounds is perhaps the best known, and is usually considered the best quality on the market; but good grades of this valuable material are also manufactured in Iceland, Newfoundland, Canada, India, the Philippine Islands, Venezuela, Brazil, the East and West Indies, and the United States.

Raw Materials

The famous Russian isinglass is made from the sounds or swim bladders of several varieties of sturgeon (*Acipenser huso* or beluga, *A. ruthenus* or sterlet, *A. sturio* or common sturgeon, *A. stellatus* or starred sturgeon), catfish (*Silurus glanis*), and carp (*Cyprinus carpio*), which are caught in the Volga and other rivers, in the Caspian and Black Seas, and in the Arctic Ocean. In Iceland cod and ling sounds are the chief source of isinglass. In Newfoundland, Nova Scotia, and New England hake and cod sounds are used for the manufacture of this material,

mostly the former. In Venezuela and Brazil the *Siluridae* are the chief source of isinglass.

Isinglass is merely carefully washed and dried fish sounds made into special forms by mechanical means. The fish sound, also called the air bladder or swim bladder, is a hollow compressible sac, containing air, situated in the abdominal cavity just below the vertebral column. Its principal function is mechanical; since it is compressible, it serves to regulate the specific gravity of the fish and enables it to rise and sink or to maintain its level in the water. The size of this organ varies greatly in different species; in sturgeon, hake, catfish, and carp it is large and well developed. In some fish the sound is securely fastened to the backbone, the intestines, and the abdominal wall, while in others it is nearly loose in the abdominal cavity. The swim bladder consists of several tunics, the outer layer of which is thick and fibrous; the collagen contained in this layer is the source of isinglass. The inner layer of tunics is thin, contains crystalline substances, such as guanin, and often has a silvery luster.

No complete analyses of fish sounds have been published; but the composition of the fresh sound probably does not differ greatly from that of the prepared isinglass as washing and cleaning removes only a small amount of membranous material and dirt. The analyses of the prepared isinglass are presented in Table 116.

Methods of Manufacture

Russian Methods. If fresh sturgeon sounds are used, they are split open and carefully washed either in cold or warm water to remove the blood, membranes, and any adhering extraneous matter. If the sounds have been previously preserved by drying, they are soaked in water for several days, with frequent changes of water to soften them and permit the removal of membranous matter.

The cleaned sounds are treated in various ways depending upon the form of isinglass desired. Common forms of Russian isinglass are long-staple, short-staple, leaf book, and cake isinglass.

In preparing leaf isinglass in the U.S.S.R. the thoroughly washed sounds are cut longitudinally into sheets which are laid out, inner side up, to dry in the sun. When partially dry the inner layer, which consists of pure isinglass, is removed from the coarser external layer. These sheets (the inner layer of the sounds) are flattened with pressure and then dried. When dry they are tied into packages, weighing about 20 oz. each. The external layers of the sounds are used chiefly for glue-making.

The "staple" form of isinglass is produced by rolling each bladder and folding it around a few pegs set in the form of a horseshoe. Book isinglass is prepared by folding the sounds and then covering them with a damp cloth.

American Methods. The best quality of American isinglass is prepared from the sounds of hake caught in deep waters off the coast of Nova Scotia. One ton of these fish yields from 300 to 500 large swim bladders, weighing a total of 40 to 50 pounds. Hake sounds from shallow waters are smaller and of a lower grade. The sounds are removed from the fish when the hake are dressed. This operation is usually carried out on board the fishing vessel soon after the fish are caught. If the fishing grounds are far from shore, the sounds are immediately salted in barrels to prevent their putrefaction.

Upon arrival at the isinglass factory the sounds are slit open and thoroughly

washed and the black outer membrane is scraped off. The sounds are then dried in the open air, usually on large trays which may be quickly taken indoors in case of rain.

The final step in the manufacture of isinglass is carried out only during cool weather on account of the difficulty of preventing softening and putrefaction during the warmer months. The process is very simple; it merely involves the union of the sounds into a long ribbon. This is accomplished by soaking the freshened, scraped, and air-dried sounds in water for 4 to 6 hours, or until they become soft and pliable. The softened sounds are usually run into a cutting machine provided with a roller and a set of knives which chop the sounds into small pieces. These are mixed and macerated between a set of iron rollers, from which the material passes to so-called sheeting rollers—hollow iron rollers, through which cold water flows, provided with a scraper which removes all adhering isinglass. Thus the isinglass is converted into sheets ⅛ to ¼ inch thick, 6 to 8 inches wide, and of any length desired. These long sheets are finally passed through ribbon rollers until the ribbons produced are $\frac{1}{64}$ inch thick, the width being the same as that of the sheets. The ribbons must be quickly dried to prevent putrefaction. This is accomplished in a few hours by suspension in moderately warm, light rooms. The ribbons are then rolled on wooden spools into coils weighing less than a pound each.

Composition and Properties of Isinglass

Isinglass does not dissolve in cold water, but merely swells slowly and absorbs some water, though not nearly the amount that would be taken up by a similar weight of gelatin. Isinglass has been popularly considered to be pure gelatin, but it is really collagen and does not become gelatin until after it has been heated with water. Under these conditions it hydrolyzes to form gelatin, which dissolves and upon cooling forms a tough gel closely resembling those formed by cooling animal-gelatin solutions. If this gel is dried, it is then found to possess all the properties of hide or bone gelatin; it will be clear and almost colorless and will make a glue of great adhesiveness. Isinglass always has a distinct fishy odor. It is insoluble in alcohol.

Isinglass should contain but little ash and a low percentage of matter insoluble in hot water. The best grades of Russian isinglass have less than 0.50 per cent of ash and not more than 3.0 per cent of matter insoluble in hot water.

Since isinglass is very valuable, attempts are often made to adulterate it with gelatin, blood fibrin, agar-agar, and several other substances. Gelatin is sometimes rolled between layers of isinglass. This adulteration may be easily detected by microscopic examination of the jelly formed by soaking the material in water: the isinglass retains its fibrous structure whereas the gelatin does not.

Bogue (1922) carried out detailed analyses of Russian isinglass. His results are given in Table 116 (p. 536).

Uses

The most important use of isinglass is in the clarification of wine. White wines are sometimes clarified by treatment with isinglass. The fining process is simple. The isinglass is first swollen in water and then in wine until it is nearly transparent. It is thoroughly beaten with more wine, after which a little tartaric acid is added.

TABLE 116. NITROGENOUS CONSTITUENTS OF RUSSIAN ISINGLASS.

	Per Cent
Protein N	91.0
Proteose N	4.4
Peptone N	4.5
Amino acid N	0.1
Total	100.0

DISTRIBUTION OF AMINO-ACID GROUPS IN PROTEIN OF RUSSIAN ISINGLASS

	Per Cent
Ammonia N	3.98
Melanin N	0.68
Cystine N	0.00
Arginine N	14.20
Histidine N	2.33
Lysine N	6.06
Amino N in filtrate	58.65
Nonamino N in filtrate	13.59
Total	99.49

The isinglass is then strained through linen and stirred into the bulk of the wine. As the solution is not heated, the isinglass does not dissolve. Thus, although the isinglass is disintegrated into a finely divided suspension, its original fibrous structure is not destroyed. As this finely divided suspension settles slowly to the bottom, it entangles in its netlike meshes the colloidal bodies that produce undesirable turbidity in the wine. Only a small amount of isinglass is required to clarify a large quantity of wine: a single ounce of isinglass will usually clarify 200 to 500 gallons of wine in 8 to 10 days.

Formerly isinglass was used for the preparation of edible jellies and in the manufacture of confectionery; but since high-grade gelatin is now relatively inexpensive, this use has become obsolete, as have also most of the uses of isinglass as an adhesive and as a size.

Isinglass is still used to a limited extent in the manufacture of court plaster. Other uses are in the preparation of special cements, as a constituent of a waterproofing composition, and for various other miscellaneous purposes.

REFERENCES

Bogue, R. H., "Properties and Constitution of Glues and Gelatin. IV," *Chem. Met. Eng.*, **23**, 154–158 (1920).

Bogue, R. H., "Isinglass," *Chem. Age.*, **30**, 183–184 (1922).

Bogue, R. H., "Chemistry and Technology of Gelatin and Glue," New York, McGraw-Hill Book Co., 1922.

Delmonte, J., "Technology of Adhesives," New York, Reinhold Publishing Corp., 1947.

Feener, S. L., and McFee, E. P., "By-products of the Fishing Industry," *Food Technology*, **3**, 211–212 (1949).

Lovern, J. A., "By-products of the Fishing Industry," *Chem. and Ind.*, **56**, 75–81 (1937).

Smith, L. F., "The Production of Glue from Fish Waste," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **3**, 5–8 (1929).

Smith, L. F., "Large-Scale Production of Fish Glue," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **7,** 6–8 (1930).

Smith, L. F., "Fish Glue from Fish Waste," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **9,** 23 (1931).

Tarr, H. L. A., "Possibilities in Developing Fisheries By-Products," *Food Technology,* **2,** 268–277 (1948).

Tressler, D. K., "Manufacture and Properties of Fish Glue," *Chem. Age,* **29,** 173–175 (1921).

White, G. F., "Fish Isinglass and Glue," U. S. Bureau of Fisheries *Doc.,* **892** (1917).

CHAPTER 25

Manufacture of Leather from Marine Sources

Introduction

The pelts of animals have been utilized by man for his comfort and protection from time immemorial, but through all these ages practically no consideration was given to the use of skins from fish. It is true that certain kinds of marine leather have found limited use, but such leather has been derived from the seal, walrus, and porpoise, the hides of which closely resemble those of land animals. Improved methods of tanning aquatic animal hides have resulted in the use of the skins of sharks, rays, and some species of fish in the manufacture of marketable leather. In dealing with this subject, therefore, it seems wise to consider first those skins which have been the longest in use and finally those of more recent introduction.

Sealskins

In discussing this subject we must at once divide sealskins into those used for furs and those used for the production of leather. As the conversion of the pelts into furs is described in Chapter 34, these methods will not be considered here. The hair seal has no under coat of fur and is, therefore, not used in the manufacture of fur articles.

Hair Seals. Hair seals (see Chap. 34) are hunted extensively in the Maritime Provinces of Canada. While there are several species in this area, the Bedlamer or Harp Seal is the most important economically. The hides are used in the manufacture of leather, and the heavy under layer of blubber is rendered into a high-grade oil for industrial purposes.

These seals are captured during December and January by means of a net, or they may be shot with a rifle; the use of a shot-gun in hunting them is likely to result in an inferior and unacceptable pelt because of the holes made by the shot. After killing they are removed from the water and skinned as quickly as possible to prevent damage to the skin.

They are skinned either on the boat or at the shore station. The flippers are first removed, leaving only a small hole. A skillful skinner will not leave any knife cuts too close to the skin which may show up later. The skins are usually frozen and stored in a shed out of the weather until market conditions are favorable for their sale.

Depilation. On arrival of the skins at the tannery the first step is to wash them to remove salt and dirt; if they have not been previously blubbered, the excess fat must be eliminated. To aid in removing the blubber the skins are soaked in water containing a small amount of sodium carbonate, and the stock is then worked over a rounded beam with a blunt knife. The fleshed or blubbered skins are then ready for depilation.

This consists in treating the skins in a paddle vat with water containing 10 per cent by weight of the hides of slaked lime and 2 per cent by weight of the hides of sodium sulfide. The action of the solution is to swell the fiber bundles, remove the cementing material, and loosen the hair and epidermis. In addition to this the lime has a certain action upon the fat, partly saponifying it and causing it to be more easily eliminated. A solution of arsenic sulfide and sodium hydroxide is sometimes used as an accelerating agent.

The time consumed in depilating depends somewhat upon the nature of the skin, but more especially upon the product to be manufactured. Skins to be used for oil tannage, where softness is desired, are given a fairly long liming. The production of fancy leather, used in making handbags, suitcases, and brief cases, requires a shorter liming period. The usual method of procedure consists in placing the skins in a vat containing a mixture of lime and sodium sulfide. The skins are passed to stronger solutions from day to day, and, finally into very strong lime solutions to which no sodium sulfide has has been added. This gradual increase in the strength of the solution prevents "case hardening" of the hide.

When the hair has become sufficiently loosened to rub off with the hand and the skins are in a properly plumped condition, they are placed over a beam and the hair and epidermis are removed with a blunt knife. In place of the hand operation dehairing machines are now commonly used for this purpose. After dehairing, the stock is washed in drums with running water until perfectly clean.

Bating. To remove the lime which has been absorbed during depilation and to bring the skins to a soft and flaccid condition again they must be bated. This operation formerly consisted in running the skins in a warm fermenting infusion of pigeon or hen manure. In recent years, however, this objectionable procedure has been entirely superseded by more scientific methods, in which a combination of chemical and enzyme action is utilized to secure the desired results. Bating consists essentially of immersing the hides in a solution of ammonium chloride or sulphate as the deliming agent. The solution also contains pancreatin, an enzyme for the removal of certain proteins, chiefly elastin, and improves the color of the grain. The ammonium salt adjusts the pH and activates the enzyme. This solution reduces the swelling of the hide produced by the previous treatment. The time of bating depends upon the product to be manufactured, but it may be said that the longer the bating the softer the resulting leather.

Vegetable Tanning. Most hair sealskin leather is prepared by the chrome method, which is generally used for light-weight leathers. One method, which requires vegetable tannin and gives very good results, consists in milling the skins for one hour in a 10° barkometer solution of quebracho extract. This serves to set the grain. The skins are then transferred to a vat containing a 12° liquor, the strength of which is gradually increased to 30°. They remain there about a week, or until tanned. When tanned the skins are milled for 2 hours with a strong sumac liquor and, after being set out, are hung up to dry. The dried skins are dampened in water, set out again, sometimes shaved, and, while yet moist, are colored as desired. The colored skins are then usually tacked out on boards to dry again.

Chrome Tanning. This method is used where it is desired to produce a light-weight soft, flexible leather. The chemical and physical mechanism of chrome tanning is not well understood. In its operation a chromium salt is used to replace

the vegetable tannin. The chrome solution is freshly prepared by slowly adding a solution of glucose to sodium chromate or by bubbling sulfur dioxide into it until the reduction is complete. The hides are placed in the chromic sulfide solution in a rotating drum for 5 or 6 hours until the tanning operation is completed.

The chrome process is much more flexible since concentration and time of treatment can be varied almost infinitely. This makes it possible to produce a wide variety of leathers, which find many applications.

Finishing. The skins on being stripped (taken from the boards) are usually given a coat of season, composed of oils or fats, and while in a damp condition are rolled on the jack. When a very bright finish is required, the stock is again seasoned with a mixture containing blood albumen; when this season is bone dry, the skins are subjected to friction on the glazing jack. To bring up the grain so characteristic of sealskin leather the stock is boarded by hand or on the machine. This consists in rolling the skins in such a manner as to produce miniature wrinkles running at different angles along the grain.

Walrus Skins

The same procedure as for sealskins is carried out for this class of leather. The resulting product is too heavy for ordinary purposes and must be split to the weight desired. Very few walrus skins are available for commercial leather manufacture as they are protected by law.

Sharkskins

Sharks, like other fish, carry a protective coating; but unlike the hair-bearing creatures this coating takes the form of scales, or a calcareous deposit known as "shagreen." Before the skins can be utilized for leather, the shagreen, like the hair and epidermis of land animals, must be removed. The earliest method for removing it consisted in scraping the surface with a heavy rasp or file. This operation, as may be well imagined, was time-consuming, very laborious, and exceedingly uneconomical. The leather resulting from this process was not a commercial product and found no ready market on account of its unsatisfactory appearance. A certain amount of raw sharkskin was used for abrasive purposes and for sword hilts; but with the lessening demand for swords and the introduction of cheap abrasives its application for those purposes is a thing of the past.

The first real advance in the production of sharkskin leather on a commercial scale dates back to 1919 and 1920 when Kohler developed and patented a process for removing the shagreen from vegetable-tanned shark skins. Rogers (1921) developed and patented several processes for removing the shagreen from the raw skin. These patents were assigned to the Ocean Leather Company, which has done more than any other concern to place this industry on a stable basis. In fact the only problem confronting the industry today is that of securing the necessary quantity of skins to meet the ever-increasing demand for the finished leather. Often the hides of sharks are not of sufficiently high quality to be suitable for tanning. Many shark hides show the results of fighting and are deeply scarred.

Catching. Several methods are employed in shark fishing, one of which consists in the use of gill nets. This is more commonly used on the Pacific Coast. These nets are about 300 yards in length and about 12 feet deep. They are anchored across the path known to be followed by food fish; as the meshes are

8 inches in diameter, any ordinary fish will pass through. Since the sharks following in the wake of the fish are so much larger, they become entangled in the meshes and are so retained. The catch of course varies with fisherman's luck, and may be from nil to any number. Three men comprise the crew of a fishing boat,

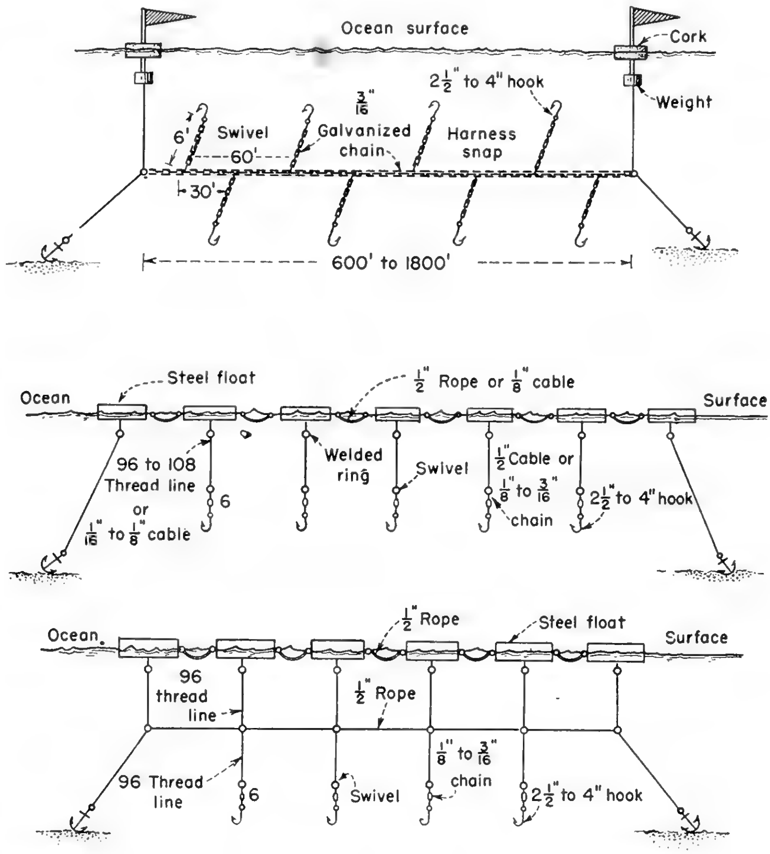


Fig. 25–1. Different types of gear used in the shark fishing industry.

and the best boat for the purpose is the Seabright dory. In hauling the net one end is gathered up and the boat pulled alongside; the shark is then brought to the surface, and with a sharp blow on the head is rendered harmless. A hook is then placed in the mouth and the shark is pulled aboard by means of a small derrick.

Considerable success has been experienced in catching sharks by means of set lines. These lines are made up of ground lines composed of sections of $\frac{3}{16}$-inch galvanized chain, 600 to 1,000 feet in length. At 30-foot intervals a 6-foot length of the chain, fitted with swivel harness snaps and a large shark hook is attached. The line is anchored at both ends and marked with flag buoys. One boat with 4 men can tend 1,200 to 1,800 feet of line per day.

Removal of the Skin. On board the vessel or on arrival at the dock the fish are at once skinned. This is done by cutting down the back from head to tail; by means of short strokes of the knife the skin is worked off the side and by a rolling motion is separated from the belly. This method of skinning gives a uniform pattern of a V-shaped design which is a solid skin, except for the opening at the

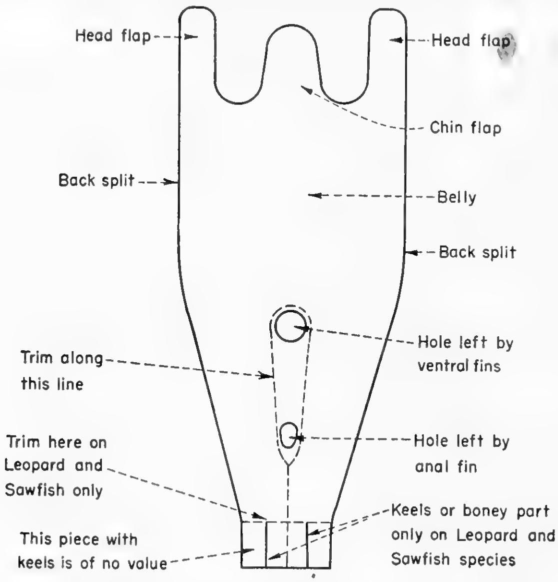


FIG. 25–2. Hide after being removed from carcass.

pectoral fins. At some stations the skin is stripped off by using a tripod and utilizing the weight of the fish as an aid in separating the pelt. The flayed skin is next worked with a sharp knife over a rounded beam to remove the adhering flesh. When properly cleaned the skins are given a liberal coat of salt and placed in piles to cure. When the cure is complete, the skins are rolled into bundles for shipment to the tannery.

Tanning Operations. As the skins arrive at the tannery, they are placed in pits containing fresh water, which serves to soften them and remove the salt. They are then transferred to lime liquor in order to open the fiber bundles and remove the cementing material, the same methods being followed as for animal skins. As in the handling of hides they are fleshed on the machine and then bated to remove the excess of lime and open up the stock.

Vegetable Tannage. If the skins are to receive a vegetable tannage, they are placed in a paddle vat containing a solution of tanning extract. The strength of the liquor influences the resulting product, the same precautions being observed as in the tanning of animal hides. When the skins have absorbed the required amount of tannin, they are removed from the paddle vat and washed. At this stage of the process the shagreen is removed by milling with an acid solution, the skins then being well washed to remove the excess of acid. They are finally fat-liquored to prevent hardening and are hung up to dry.

Finishing Operations. The dried skins are dampened back with water and ether, colored with dyes or pigment-finished. The final finishing is done on a roll-

ing or glazing jack, or on a brush machine as desired. Either a smooth or shrunken grain may be obtained by adjusting the tannage. The shrunken grain is especially in demand as it produces a very pleasing article when manufactured into bags and cases.

Chrome Tannage. In the manufacture of chrome-tanned sharkskin leather the shagreen must first be removed, after which the skins are pickled with salt and sulfuric acid and then run in a solution containing basic sulfate of chromium and salt. This operation is usually carried out in a drum, and the test to determine when the stock is tanned depends upon the fact that a chrome-tanned leather will not curl when placed in boiling water. When thoroughly tanned the skins are horsed up overnight to allow the chrome to set, and are then returned to the drum for neutralization. This operation consists of running the skins with a solution of sodium bicarbonate and clear water. The chrome-tanned stock must be shaved to secure an even condition on the flesh side. This is done on a machine which carries a set of spiral knives; as the knife revolves, the skin is placed against the cutting edges.

Coloring. To color chrome-tanned leather the stock is first run in a solution containing tannic acid, for which purpose sumac or quebracho extract is usually employed. This material acts as a mordant for the dyes used to produce the color. The time in the mordant is about ½ hour and about the same time is required for the color. After coloring, the skins are fat-liquored with a sulfonated oil and then hung up to dry. On coming from the dry loft the skins are packed in damp sawdust to moisten slowly, or as the tanner calls it, "to sammie." When in the proper condition, they are worked on a machine, called a "staker," to soften and stretch them. When well stretched and as soft as desired the stock is tacked out on boards and again allowed to dry. On removal of the dry skins from the boards, or stripping, they are given a coat of seasoning and are then rolled or glazed as the demand may dictate.

Estimating the Value of Shark Hides. Shark hides are bought on measurement (Anon., 1935). The part of the hide over the tail itself and that over the head where the pores are are valueless. These parts are not recorded in the measurements nor paid for, so that it is a waste of time to skin them off. The leopard shark and sawshark have two keels or bony ribs, one on each side running from the tail along the body for 4 to 16 inches. This part of the hide of these two sharks is valueless and should be cut off.

Defects that Reduce Value of Hides. *Holes.* These may be due to fighting scars, harpoon scars, and butcher cuts. There is nothing that can be done about the fighting scars, but the way to avoid butcher cuts has been described under skinning and fleshing.

Sour Spots. This really means that the hide is rotten in some place. The most frequent causes of sour spots are delay in skinning after death, lack of quick and thorough curing, poor quality salt, or contact with fresh water.

Burnt Hides. Deep wrinkles in the hides cannot be removed during the tanning process, and good marketable leather cannot be produced from hides with deep wrinkles. (Do not confuse these deep wrinkles, produced by faulty handling, with the naturally occurring, shallow wrinkles, always found in the hide of the tiger shark.) Such hides are sometimes called "burnt" hides. Sometimes these deep wrinkles are caused by not laying the hides flat during curing and, as is

more often the case, by exposing the hides to hot sun. Sometimes they may become burnt or overheated during storage. To avoid this danger they should be moved occasionally so that the air can get at them. A burnt hide is valueless.

Thin Bellies. At certain times of the year some sharks, particularly the nurse shark, have "thin bellies." There is nothing that can be done about this. Another cause of "thin bellies" is improper skinning. The hides are pulled off the sharks, leaving some of the hide substance on the carcass. This cause of "thin bellies" is easily avoided by following the instructions already given for skinning.

Selling Hides. To give an idea of the price which may be expected the price list of one of the large purchasers as of 1943 is given in Table 117.

TABLE 117.

SCHEDULE OF PRICES AND CLASSIFICATION ON NURSE SHARK HIDES

Hides measuring	35 in.	and up to and including	49 in.	$0.85
ditto	50 in.	ditto	59 in.	1.10
ditto	60 in.	ditto	64 in.	1.40
ditto	65 in.	ditto	69 in.	1.80
ditto	70 in.	ditto	74 in.	2.10
ditto	75 in.	ditto	80 in.	2.45
ditto	81 in.	ditto	90 in.	3.10
ditto	91 in.	ditto	100 in.	3.65
ditto	101 in.	ditto	110 in.	4.10
ditto	111 in.	ditto	120 in.	4.75

SCHEDULE OF PRICES AND CLASSIFICATION ON SHARK HIDES OF OTHER SPECIES

Hides measuring	35 in.	and up to and including	49 in.	$0.70
ditto	50 in.	ditto	59 in.	0.90
ditto	60 in.	ditto	64 in.	1.15
ditto	65 in.	ditto	69 in.	1.50
ditto	70 in.	ditto	80 in.	2.00
ditto	81 in.	ditto	90 in.	2.50
ditto	91 in.	ditto	94 in.	2.90
ditto	95 in.	ditto	104 in.	3.35
ditto	105 in.	ditto	115 in.	3.90
ditto	116 in.	ditto	125 in.	4.55
ditto	126 in.	ditto	135 in.	5.50

F.O.B. tannery, payment after arrival and inspection at plant.

The hides are graded and the above prices apply as follows:

No. 1 Hides: Full price, plus 20 per cent bonus. Perfect hides, having no holes and no sour (rotten) spots.

No. 2 Hides: Full price. Hides having not more than 3 holes, or not more than 1 sour spot.

No. 3 Hides: 40 per cent of full price. Hides having 4 or more holes or more than 1 sour spot.

No. 4 Hides: No value. Hides having numerous holes over the entire surface or having a large number of sour spots over the entire surface, making the hide worthless.

These measurements are based on the length of the hides, skinned and trimmed. If the extra-long tails are not cut off, deductions are made accordingly. Holes refer to butcher cuts, harpoon holes, fighting scars, etc.

The foregoing is a general description of how the hides are graded, subject, however, to adjustments according to the length and width of the holes and the size of the sour spots. Generally speaking, if there are only a few cuts, or one or two sour spots on the edges of the hide, these can be trimmed out; but if there are a number of sour spots or holes in the center of the hide, the value is reduced over 50 per cent.

Ray Skins

Many species of fish are included under this head (e.g., skates, devilfish, and sawfish). Their skins resemble those from sharks in that they carry a layer of shagreen and must be handled in a manner quite similar to that described for sharkskins.

Porpoise Skins

Porpoise, dolphin, and blackfish—names often applied to the same species of marine mammals—have long been utilized for leather. Their skin is very heavy, and under the dermis there is a thick layer of blubber which must be removed before tanning. This is done in a manner similar to that described under sealskins. Recent investigations, however, have shown that this fatty layer may also be easily separated on the belt-knife splitting machine and the time factor therefore greatly reduced. The blubber, which is separated from the hide proper, is heated in kettles or rendered to obtain its oil content. The skin from the porpoise, as well as from the other species, has on its outer surface a peculiar covering known as the "rubber layer." This layer is readily separated by liming and can be easily removed over the beam or on the dehairing machine. After beaming, the limed skins are bated to remove the excess of lime, and may be tanned either by the vegetable, chrome, or oil process.

Tanning Processes. In the vegetable tannage of porpoise skins the bated stock is placed in a paddle vat containing a dilute tannin extract. As the union of the tannic acid with the hide substance progresses, more and stronger liquors are required. This strength is obtained by the addition of concentrated extracts to the paddle. The time required for tanning is from 7 to 10 days, and the tanned stock may then be finished in any way desired. In recent years considerable porpoise leather has been made to imitate Cordovan; it produces a very worthy substitute.

Porpoise Lace Leather. One of the chief uses for porpoise skins in the past, and to a certain extent at present, is in the production of lace leather. This is a very strong material used for lacing machinery belting. The method of producing it involves first tanning the stock, after coming from the bate, with a mixture of alum and salt. To accomplish this the skins are run in a drum with a mixture of about 5 per cent aluminum sulfate and 5 per cent common salt, to which is added about 0.05 per cent sodium bicarbonate. The skins readily take up this mixture. When penetration is complete, they are hung up and allowed to become bone dry. The longer the skins remain in this dry condition, the better the resulting leather. After removing from the dry loft the skins are dampened slightly with

water and placed in piles to "sammie," or to become uniformly moist. When in the proper moist condition the stock is transferred to a mill and 4 per cent of cod oil introduced. The drum is set in motion, and after it has run for 1 hour another 4 per cent of oil is added. At the end of 2 hours more all the oil should have been absorbed; then a third and final portion of 4 per cent is placed in the drum. The final milling should require about 3 hours, after which the skins are taken out and piled down over night.

The following day the stock is hung up and allowed to become thoroughly dry. The skins are then dampened uniformly and again piled down to temper. This time considerable heat is generated as a result of oxidation of the oil; therefore, care must be taken to avoid overheating and consequent damage to the stock. At the end of 24 hours the skins are again hung up to dry in a room, the temperature of which is about 140° F (60° C). If oxidation is not complete, the stock is again dampened, tempered, and stoved. By this time the skins should be thoroughly tanned and are dampened, oiled off with mineral oil, and rolled.

Hair-Seal Products

Hair seals do not have the fine under fur that characterizes fur seals, and comparatively little use is made of these skins in clothing; a few are used in the manufacture of sport garments, but the demand is extremely limited. Their primary use is as leather for the manufacture of small bags, wallets, and similar articles. Some are made into "climbers" for skis.

Sealskins taken in the Newfoundland fishery are landed with the underlying layer of blubber intact. This is removed, either by hand or by machine, and the oil is extracted by steam, after which it is stored in settling tanks. Hair-seal oil production in Newfoundland reached its maximum in 1926 when more than 336,000 imperial gallons were produced. The loss of the United States market in 1934 and subsequent economic difficulties led to a decline in this production to only 34,000 imperial gallons in 1945. The principal use in the United States for hair-seal blubber oil was in soap manufacture, although considerable quantities were used also in the leather industry and in lubricants.

Hair-seal carcasses are not used in the Newfoundland fishery, except occasionally as food by the sealers. The nature of sealing operations makes it impractical to pick up the carcasses after the kill, and they are left behind on the ice. Since they could be reduced to meal and oil by the same methods employed in the utilization of fur-seal carcasses at the Pribilof Islands, the Newfoundland hair-seal fishery may some day find factory ships in operation for the more complete utilization of the resource.

Miscellaneous Leathers

Whale-Hide Leather. The hide of a whale, like the skin of a porpoise, carries a very heavy blubber. The hide itself is much thicker than porpoise, but up to the present time no satisfactory use has been found for it. It may be tanned by the same methods as porpoise leather.

Alligator Leather. The natural markings of alligator hides give them an exceptionally attractive appearance when tanned. The leather made from them is soft and pliable, yet tough and wear-resistant. They are valued for hand luggage, ladies' bags, billfolds, and shoes, and are readily dyed and take a high polish.

They are tanned by either the chrome or vegetable process, depending upon the use intended. In many instances the heavy keratoid portion of the hide, down the center of the back, is removed when the hide is made into leather. In the younger alligators this portion is used for decorative purposes after it has been softened by the tanning process. Alligator hide leather is increasing in value as a result of the reduction of the population by intensive hunting, and the drainage of many swamp areas.

Food-Fish Skins. As in the case of sharkskins the value of a hide is based to a considerable extent upon the size of the skin. This alone eliminates the wide usage of the skins of food fish, although they are used to some extent in the manufacture of novelties, ladies' shoes, and decorations for handbags, etc.

The skins of several species of large fish are those generally tanned. These include cod, salmon, red snapper, grouper, and halibut. The chrome process is generally used since it produces a softer, more pliable leather than any of the vegetable tannins. The skins can be dyed almost any color desired, and have an attractive natural design on the surface resulting from the removal of the scales from the follicles.

The tanning operation is somewhat simpler than for shark and similar skins and sealskins. The scales are first removed. If the hides have been cured by salting, they are soaked in a series of fresh-water baths to remove the salt. The liming treatment is not generally necessary since there is no hair to remove, but a sodium carbonate bath is used to saponify a portion of the oil or fat usually found in small amounts in the skin. The sodium carbonate treatment also "plumps" the skins so that they swell and absorb the tannin more readily. In some cases both lime and sodium carbonate are needed to accomplish the desired results. Bating and tanning are accomplished by either the vegetable or chrome methods as described later in this chapter.

Salmon Skins. One large canning firm in the Pacific Northwest has devised a machine for removing the skins of salmon prior to canning. This machine is constructed so that the skins are removed in one large piece without injury. Salmon skins are much heavier than those of many other species of fish and are suitable for use in the leather industry without the reinforced backing required when lighter skins are used. The skins are large enough for tanning to be economically feasible, and they are naturally decorated by the pattern resulting from the removal of the scales. These skins have been tanned by both the chrome and vegetable methods. It is possible that in the future salmon skins may become a large source of leather material.

Fish Intestines and Stomachs. The large intestines of the whale have been suggested as a source of leather. Considerable work on this material has been carried out by various investigators, and the results obtained indicate that it may be used to advantage for certain purposes. The intestines of the porpoise have also been investigated, and from them it has been possible to produce a very satisfactory substitute for catgut, used in producing surgical sutures and for musical instrument strings. Some work has been done upon shark stomachs, but nothing definite has yet been accomplished. Shark and ray tubes, however, have been tanned, and the resulting leather has been shown to be of commercial values, though not used at present.

Chemical Reactions Involved in Tanning

In the study of leather manufacture, like every other manufacturing process, the chemical reactions involved form the basis upon which a complete understanding depends. Let us, therefore, consider the reactions taking place in the order of their occurrence.

Liming. In removing the hair or plumping the stock a solution of milk of lime is generally used. Lime is obtained by "burning" limestone or calcium carbonate, whereby the gas (carbon dioxide) is driven off and calcium oxide remains. This calcium oxide, when treated with water, is converted into calcium hydroxide which, when mixed with water, forms a suspension known as milk of lime. Calcium hydroxide acting upon the hide substance forms soluble compounds with the albuminous materials, thus causing partial hydrolysis with a resulting swelling and opening of the fiber bundles. To a certain limited extent, also, the lime tends to saponify the fatty matter, thus making its removal less difficult in the subsequent operations.

Bating. The action of the bate through the ammonium chloride present is to remove the excess of lime, and a depleting effect upon the hide substance is brought about by the enzymes which it contains. The removal of the lime and the depleting action produce the desired softness and flaccidity required before actual tanning.

Vegetable Tanning Materials. Tannic acid is the primary substance contained in tanning solutions. It combines with the gelatinous substance of the hide, forming an insoluble, nonputrescible product. Tannic acid alone, however, will not make a satisfactory leather as it requires the presence of other substances, called "non-tans," to secure the desired results. Sources of vegetable-tanning agents are: the barks of numerous trees, such as oak, chestnut, and hemlock; the wood of some trees, such as quebracho; and the leaves of certain shrubs, such as sumac. The real tanning substances are obtained by extraction with water from all these materials.

Chrome Tannage. In the production of leather by the chrome process the active substance is basic sulfate of chromium. This compound may be produced in various ways, but in practically all cases it results from the reduction of sodium dichromate in the presence of sulfurous acid. The tannage is due to a deposition of chromium hydroxide and lower basic substances about the fiber bundles. Chrome tannage has the advantage over vegetable tannage in that the time required is much less and the resulting leather has characteristics which are very desirable for use in the manufacture of shoes.

Dyeing and Finishing. In dyeing leather natural colors as well as coal-tar dyestuffs are employed. For bright shades the basic dyes are most commonly used, but for certain purposes both acid and direct colors are applied. Within the past few years pigment finishes have met with considerable favor and are now being used to a very large extent. To give leather the proper strength, fullness, and desired appearance it is necessary to introduce certain fats and oils at various stages in the process of manufacture, and to apply special finishes for producing a bright or dull appearance as the demand may indicate. The most common oils and fats are cod oil, neatsfoot oil, and degras, while the finishing materials consist of gum tragacanth, Irish moss, egg albumen, shellac, gelatin, and various alginates.

To give all the details necessary in producing leather from the various skins mentioned in this chapter would take more space than can be devoted to the subject in a book of this character.

REFERENCES

Anon., "Guide to Commercial Shark Fishing in the Caribbean Area," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **137** (1945).

Anon., "Leather from Salmon Skins," *Pacific Fisherman*, **47**, No. 3, 57 (1949).

Anon., "The Harp Seal, Its Exploitations and Preparation," Department of Fisheries, Province of Quebec, *Circ.*, **1** (1949a).

Kates, H. G., "Luggage and Leather Goods Manual," New York, Luggage and Leather Goods Mfgs. of America, Inc., 1948.

McLaughlin, G. D., and Theis, E. R., "The Chemistry of Leather Manufacture," New York, Reinhold Pub. Corp., 1945.

Orthmann, A. C., "Tanning Processes," New York, Hide and Leather Publishing Co., 1945.

Rogers, A., "Preserving Shark Skins," U. S. Pat. 1,395,773 (1921).

Rogers, A., "Treating Shark Skins," U. S. Pat. 1,412,968 (1922).

Rogers, A., "Industrial Chemistry," 5th Edition, New York, D. Van Nostrand Co., Inc., 1931.

Shreve, R. N., "The Chemical Process Industries," New York, McGraw-Hill Book Co., Inc., 1945.

Smith, P. I., "Principles and Processes of Light Leather Manufacture," New York, Chemical Pub. Co., Inc., 1942.

Smith, P. I., "Standard Handbook of Industrial Leathers," David Woodroffe, editor, London, Nat'l Trade Press Ltd., 1949.

Wilson, J. A., "Modern Practice in Leather Manufacture," New York, Reinhold Pub. Corp., 1941.

CHAPTER 26

The Oyster Industry of the World

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Introduction

Among the marine fisheries of the world the oyster industry occupies a unique position. It is the most ancient fishery, and has been in use since the beginning of our civilization by primitive peoples before they learned the art of fishing and hunting. Numerous shellheaps or so-called "kitchen middens" which dot the shores of Europe, America, Australia, and Africa tell us how important oysters and other shellfish were in the diet of earlier inhabitants of these continents. At present the oyster industry has advanced to such a point that it no longer depends on gathering wild oysters from natural rocks or reefs where they grow in the sea. Through elaborate methods of oyster cultivation the oysterman became a farmer who by his efforts and skill converted many thousands of acres of barren sea bottom into productive land under the water.

In comparison with the great fisheries of the world, like herring, sardine, cod, and others, the oyster industry contributes annually a relatively modest quantity of sea food. Its economic importance for the communities engaged in the cultivation of oysters is great, however, because the returns of oyster farming often exceed the best returns from farming on land.

World statistics of the oyster fishery are incomplete and not always dependable. There is no uniformity in reporting data by different countries and therefore comparison of the production in different parts of the world is difficult. The majority of European countries and Japan express the figures of production in metric tons, presumably referring to the total weight of oysters in shells. The United Kingdom and France record the actual number of oysters sold; New Zealand gives the catch in sacks, and the United States records the weight of oyster meat and the number of bushels taken. The different catch figures can be converted to a common basis only by making certain assumptions, which are difficult to verify without special studies at the places of production. No information is available at present from China and other Asiatic countries, U.S.S.R., and some of the South American republics, in which the oyster industry is not organized, although it is known that considerable quantities of oysters are consumed locally. Official information regarding oyster production in various countries is summarized in Table 118 (p. 551).

Detailed statistical data of the oyster catch in the United States show that the 37,827 metric tons of oyster meat produced in 1945 were obtained from 13,476,400 bushels of eastern oyster (*Ostrea virginica*); 1,443,000 bushels of Pacific oyster

TABLE 118. OYSTER PRODUCTION IN VARIOUS COUNTRIES IN 1945, UNLESS OTHERWISE INDICATED.

Country	Annual production in Metric Tons: Total Weight	Metric Tons: Weight of Meat	No. of oysters in thousands	Sacks	Remarks
Australia	2,920				
Belgium	1				Including other mollusks.
Canada	3,375				
France			222,580		*O. edulis,* 1937.
"			1,230,660		*O. angulata,* 1937.
Germany	8				Including shrimps and crabs, 1937.
Ireland			1,516		*O. edulis.*
Japan	46,337				Produced by cultivation, 1940.
"	16,800				Landed in Japanese ports, 1945.
Netherlands	1,366				1946.
New Zealand				73,119	Dredged.
"				5,828	Rock oysters.
Norway	21				1943.
Portugal	218				1944.
Spain	468				*O. edulis,* 1944.
"	14				*O. angulata,* 1946.
Sweden	1				
United Kingdom			5,651		In England and Wales.
"			12		In Scotland.
United States		37,827			
Mexico	3,760				1946 from U. S. Fish and Wildlife Service *Fishery Leaflet* 339.

Source: "Yearbook of Fisheries Statistics," FAO, 1947, and "Fishery Statistics of U.S.A., 1945," U. S. Fish and Wildlife Service *Statistical Digest* 18 (1949).

(*O. gigas*); and 686,350 bushels of so-called Olympia oyster of the West Coast (*O. lurida*). The average yield was 5 pounds of meat per bushel. Assuming that a bushel of eastern oysters weighs 80 pounds and that of the Pacific and Olympia oysters, which have lighter shells, weighs 50 pounds, the total annual production of oysters in shells in the United States is estimated as 575,272 metric tons.

Next in importance are France (about 109,000 metric tons [1]) and Japan (63,137 metric tons). According to Raas (1948) China produces 11,200 metric tons, and other countries not listed in Table 118 (presumably including U.S.S.R.) each produce not more than 300 or 400 metric tons.

Thus, the total world production of oysters may be roughly estimated between 760,000 and 800,000 metric tons. The figure of 160,000 metric tons given by Raas (1948) as a total world production of oysters in 1937 is too low, because apparently he did not take into consideration the different methods of reporting oyster catch in various countries.

[1] Assuming the average weight of *O. edulis* and *O. angulata* is 75 g.

Species

Scientific classification of oysters is based primarily on the appearance and structure of their shell. The latter is of simple shape and lacks any prominent ornamental or sculptural characteristics, which are well developed in other mollusks and are frequently used in distinguishing various species. Furthermore, virtually all edible oysters vary greatly in size and shape, depending on the environment. They are long and narrow on soft bottom and round and flat on hard ground. Crowded conditions cause them to form clusters of grossly misshapen individuals; when they are attached to rocks, piles, or other submerged objects, their shells follow the curvature of the substratum. Because of this variability identification of the species presents considerable difficulty.

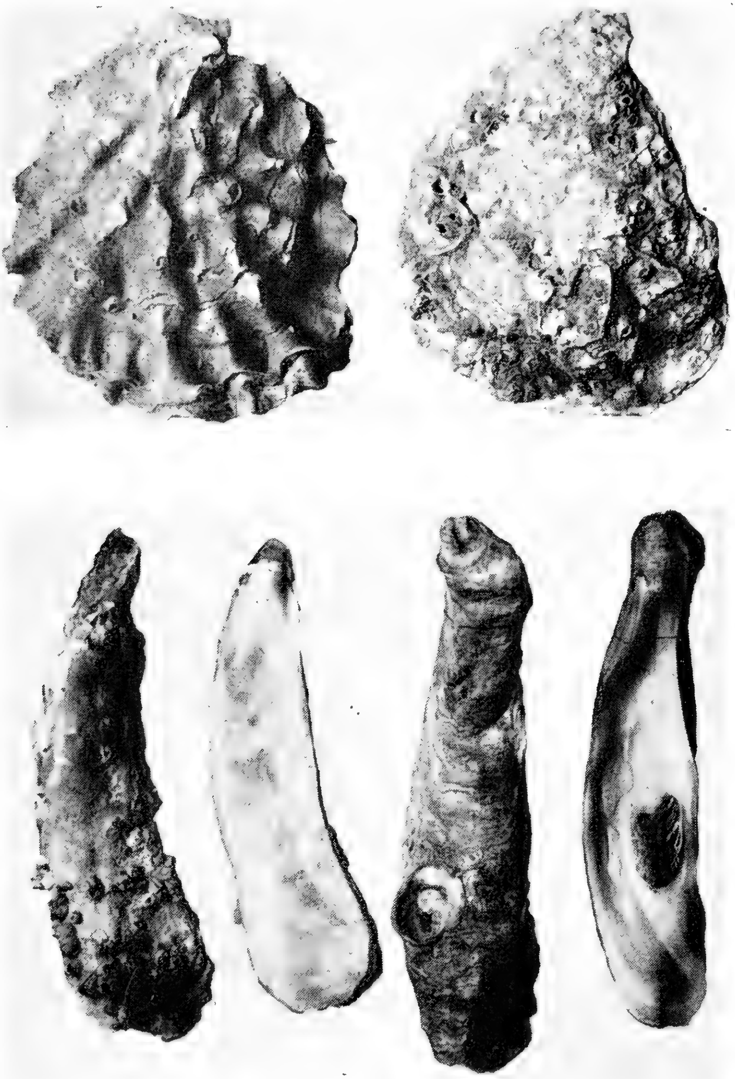
Of the large number of species of oysters described by zoologists, only a few are used in commerce. The principal edible oysters used in different countries are as follows: *Ostrea virginica* Gmelin: American oyster of the Atlantic coast; *Ostrea edulis* Linné: European edible oyster; *Ostrea* (*Gryphaea*) *angulata* Lamarck: Portuguese oyster introduced to France; *Ostrea commercialis* Iredale and Roughley, *Ostrea angasi* Sowerby: from Australia and New Zealand; *Ostrea denselamellosa* Lischke and *Ostrea gigas* Thunberg from Japan (introduced to the Pacific Coast of the United States); *Ostrea cucullata* Born: in India; *Ostrea chilensis* Philippi: found on the coast of Central and South America; *Ostrea lurida* Carpenter: so-called Olympia oyster from the Pacific Coast of the United States and Canada; *Ostrea taurica* Krynicki: cultivated in the Black Sea, Russia; *Ostrea* (*Gryphaea*) *rhizophorae* Gmelin: from West Indies.

The question whether various species of oysters may interbreed and produce hybrids has not been definitely answered, but it is known that under laboratory conditions cross-fertilization of eggs takes place between *O. virginica, O. gigas, O. angulata,* and *O. commercialis.* It is quite possible, therefore, that hybrid oysters occur in nature or that they may be produced by artificial cultivation.

Biology

The oyster belongs to the class of mollusks called by Cuvier as *Bivalvia* and more recently renamed *Pelecypoda.* The animals of this group have their bodies enclosed in a two-valve shell and have no head. Oysters differ from other members of this group by the absence of a muscular foot, which in clams and mussels serves as a powerful organ of locomotion. Having lost their foot, which is present during the larval stages, in the process of evolution oysters became sessile creatures. They live attached to rocks, pilings, and other submerged objects, or lie motionless on the bottom of the sea. They are unable to move out of the unfavorable environment or avoid danger; their only means of defense is the ability to shut their valves so tightly that the shell is hermetically sealed. A quantity of sea water which is retained in the shell cavity keeps the body moist and prevents desiccation when oysters are exposed at low water or when they are shipped long distance to the market. The ability of oysters to remain closed for several days or even weeks is a useful adaptation which helps the oyster to survive adverse conditions, such as freshets, temporary pollution of water, or exposure to strong sunlight at low tide.

Loss of locomotion and the absence of organs of hearing and vision are com-



(Courtesy U. S. Fish and Wildlife Service)

FIG. 26–1. Upper row, right, American Eastern oyster, *Ostrea virginica,* from a well cultivated oyster ground; left, Pacific oyster, *Ostrea gigas,* grown from seed imported from Japan and planted on hard bottom in Willapa Bay, Washington. Lower row, right, American eastern oyster, *Ostrea virginica,* from crowded muddy bottom of a natural reef; left, Pacific oyster, *Ostrea gigas,* from soft and muddy bottom of Puget Sound.

pensated in the oyster by a highly developed chemical sense. The organs by which the oyster tastes the water are tiny finger-like tentacles set in two rows on the edge of each mantle. When the oyster opens its shell the tentacles slightly protrude beyond the edges of the valves and guard the entrance to the shell cavity. Presence of a toxic or irritating substance makes them contract. The stimulus, if strong enough, is conveyed through the mantle to the powerful adductor muscle which contracts and closes the shell. In this way access of harmful substances is prevented and the oyster remains safe inside its calcareous home. The tentacles are also sensitive to light and react to sudden changes in illumination.

The principal function of the mantle which surrounds the body of the oyster is the formation and repair of shell. The growth of shells, both in length and in thickness, continues throughout the life of the oyster, but the rate of growing slows down with age.

Opening and Closing of Shell. The powerful muscle attached to both valves controls the closing and opening of the shell. When it contracts, the shell remains tightly closed; when it relaxes the springlike action of a hinge, a dark, elastic band of organic substance, by which the two valves are joined together forces them apart. Shell movements of an oyster can be easily recorded on paper mounted on a rotating drum. Study of such records reveals to the biologist important facts regarding the effect of environment on the behavior of the oyster. In the presence of small concentrations of harmful substances the normal muscular curve is altered, closing and opening of valves becomes irregular, and the time the oyster remains closed and not feeding lengthens. Such observations are usually made in a study of the effect of pollution on oysters.

Respiration and Feeding. Like many other aquatic animals the oyster possesses gills, a highly complex organ, which is concerned primarily with respiration. However, its function in the bivalve mollusks underwent considerable change and the gills became important parts of the feeding mechanism as well as an organ of respiration.

The gills in the oyster are located immediately under the mantle, two on each side; they may be compared to a fine sieve covered with hairlike cilia. The holes of the sieve, so-called ostia, are surrounded by relatively large cilia, which beat inward and produce a current of water which passes through tubelike structures inside the gills and is expelled through the cloaca.

The exposed sides of the gills are covered by small cilia which beat along the surface and push toward the edge of the gill the minute unicellular algae and other particles which are carried in with the current of water and settle on the gills. In feeding and respiration the oyster filters large volumes of water from which it obtains its food and oxygen. Material settled on the surface of the gills is entangled in mucus secreted by special cells and is gradually carried toward the mouth and ingested. Methods are available now (Galtsoff, 1946) for recording the amount of water filtered by the oyster. In cold water the rate of pumping slows down and completely stops at temperatures below 42° F (5.6° C). It immediately increases as the water temperature is raised and reaches its maximum at about 77–80° F (25–26.7° C).

Toxic substances discarded into water with industrial wastes retard the rate of pumping and greatly interfere with the feeding (Galtsoff *et al.*, 1947, Chipman and Galtsoff, 1949). Records made in various laboratories under different

conditions show that in clean, unpolluted water adult oysters keep their shells open and with brief interruptions pump water for 20 to 22 hours a day. The rate of pumping varies from a few quarts to a maximum of about 30 quarts an hour, with the average for the summer temperatures of about 14 to 16 quarts per hour. On that basis a single adult oyster would require about 80 gallons of sea water daily for feeding and respiration. These observations show that overcrowding of oysters should be avoided and that the grounds selected for planting of oysters should have a good exchange of water.

Digestive gland. The large, dark-colored mass of tissue easily seen if the oyster is cut across by a knife, is the digestive gland, or so-called liver. Its color is usually obscured by the mantle and by gonads, which in ripe oysters form a thick white layer of sex cells. In thin, watery oysters the dark color of the liver shows clearly through the surrounding tissues and frequently causes the purchaser not familiar with oyster anatomy some concern.

Sex and Propagation. There are two different methods of propagation. In some species, as for instance in the European flat oyster (*O. edulis*), or native Pacific Coast oyster (*O. lurida*), the eggs are fertilized inside the oyster and the ensuing larvae are retained for about 10 days. At this age they leave the parents to swim freely in the water and after a week or more settle and attach themselves to a hard surface. The other method is well illustrated by the American oyster (*O. virginica*) and the Japanese oyster (*O. gigas*). By vigorous snapping of the shell the spawning female discharges its eggs into the water where they are fertilized by sperm. Simultaneous shedding of eggs and sperm is essential for the success of fertilization, which is accomplished by mutual stimulation of the two sexes. Sperm, present in water, induces the spawning of the ripe female, while eggs shed by the female oyster secrete a substance which provokes spawning in the male (Galtsoff, 1938, 1940). Fertilization takes place before the eggs settle to the bottom, and free-swimming larvae develop within a few hours.

The sex of an oyster is unstable. Although at one instant the majority of the individuals are either male or female, changes frequently occur, especially in the oysters of the first group in which hermaphrodites are often found. In the second group the change of sex takes place in only a few individuals after the completion of the spawning and before the new gonad is developed. Young *O. virginica,* less than 1-year old, are predominantly male; but by the end of the first year the two sexes have established a 50:50 ratio.

Oysters are very prolific. Female *O. virginica* and *O. gigas* may discharge up to 100 million eggs at one shedding and may spawn several times during one season. Adverse conditions, such as freshets, abnormal temperature, and pollution of water may inhibit or completely prevent the development of gonad. Degree of gonad development and ripeness of the oyster can be easily observed by making a cut across the body of the oyster and noticing the thickness and consistency of the creamy gonad layer.

Fatness. The quality of oyster meat is primarily dependent on the percentage of solids and the content of glycogen, a carbohydrate stored as reserve food in the mantle and other organs.

Good oysters, with a high yield of meat per bushel, usually contain around 20 per cent solids, while in poor, watery ones the solids drop to less than 10 per cent. High solids content is usually accompanied by high glycogen content. Such

oysters are white in appearance and their meat almost completely fills the shell cavity. They are usually called "fat" although the actual fat content in the oyster is low. Since American oysters are commonly sold by bushels, the production of "fat" oysters with high content of solids is very important to the industry. Variation in the yield of meat, expressed in pounds per bushel, in various oyster-producing states is shown in Table 119.

TABLE 119. YIELDS OF MEAT OF MARKET OYSTERS IN POUNDS PER BUSHEL IN DIFFERENT STATES, 1945.

State	Capacity of State bushel	Variation from U. S. standard bushel	Market oysters: Yield per State bushel	Market oysters: Yield per standard bushel
	Cubic inches	%	Lbs. of meat	Lbs. of meat
Massachusetts	2150.4	—	6.51	6.51
Rhode Island	2150.4	—	7.00	7.00
Connecticut	2150.4	—	7.70	7.70
New York	2150.4	—	7.50	7.50
New Jersey	2257.3	+5.0	8.00	7.96
Delaware	2257.3	+5.0	8.04	8.00
Maryland	2800.7	+30.3	6.02	4.62
Virginia	3003.9	+39.7	6.28	4.50
North Carolina	2801.9	+30.3	4.01	3.08
South Carolina	4071.5	+89.3	4.96	2.62
Georgia	5343.9	+148.5	7.68	3.09
Florida	3214.1	+49.4	4.48	3.00
Alabama	2826.2	+31.4	5.30	4.03
Mississippi	2826.2	+31.4	5.41	4.12
Louisiana	2148.4	−0.1	4.63	4.63
Texas	2700.0	+25.6	4.74	3.78

Source: Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

High yield of oyster meat depends on several variables, such as the quality of the ground, the skill in the cultivation or oyster farming, salinity of water, and season. Unattended public reefs usually produce oysters of poor quality and very low yield.

Cultivation

Oyster culture or oyster farming probably originated from the first attempts of primitive man to gather live shellfish and place them at an easily accessible place in shallow water near his dwelling.

Thousands of years before the Christian era the growing of oysters was known in China. In Europe the Romans practiced it with great skill and bragged about the quality of the oysters served at the feasts of their emperors and nobles. In the United States the planting of oysters began about 100 years ago. As practiced at present oyster farming consists of several operations. First the bottom is acquired through lease from the state and is cleaned and planted with shells, gravel, or other material to catch young oysters. After the set is obtained and

allowed to grow for a few weeks or months, it is transplanted to deeper growing grounds. As the young oysters increase in size and require more space, they are transferred several times to new grounds until they grow to the marketable size of 3 inches or more. Finally, they are transplanted to fattening grounds where they acquire desired flavor and accumulate a large amount of glycogen. In the last operation they are harvested, washed, graded, packed, and shipped to market.

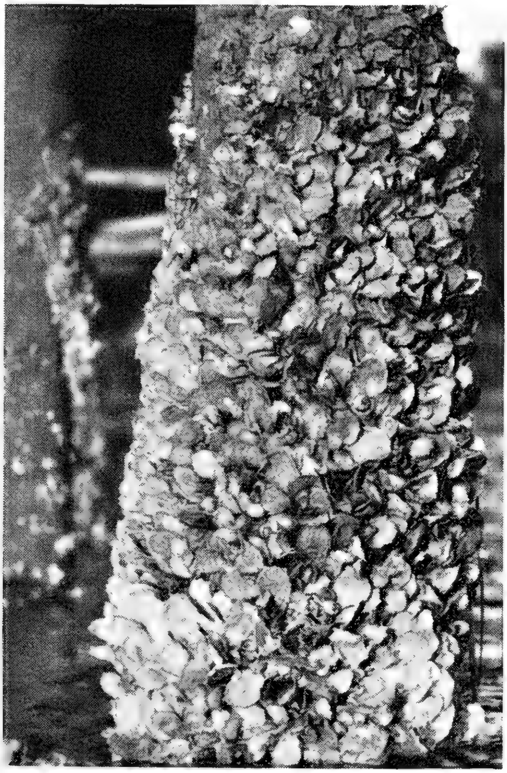


FIG. 26–2. Oysters growing on pilings.

Seed-oyster grounds are usually located in shallow water close to the shore or on tidal flats. Well-planned oyster farming requires that these grounds be kept free from accumulation of debris and be replanted with shells or other cultch every year shortly before the setting season. In some states the production of seed oysters is developed as a special and highly profitable business. Several oyster companies in New England maintain their own seed-oyster grounds and ship the young oysters to the growing grounds sometimes located in another state.

Oyster farmers in France have developed a special technique of collecting young oysters (spat) on tiles placed at low tide on flats. After a few months young oysters are detached from the tiles with a sharp knife and placed on growing grounds. For fattening the oysters farmers at Arcachon, France use shallow ponds, or "claires," filled with sea water supplied by a system of ditches. Oysters in claires feed on diatoms which thrive in them, and frequently acquire a greenish color derived from the pigment of these algae. These green oysters have a very

pleasant flavor and are greatly valued by connoisseurs. Green-gilled oysters are regularly found in the United States on certain grounds in Virginia and North Carolina. Their coloration is also due to the absorption of pigment from the algae upon which they feed. But unfortunately the prejudice against green oysters in the United States is so strong that discolored oysters cannot be marketed. This is probably because in some places along the Atlantic Coast, as for instance along the

(Courtesy U. S. Fish and Wildlife Service)

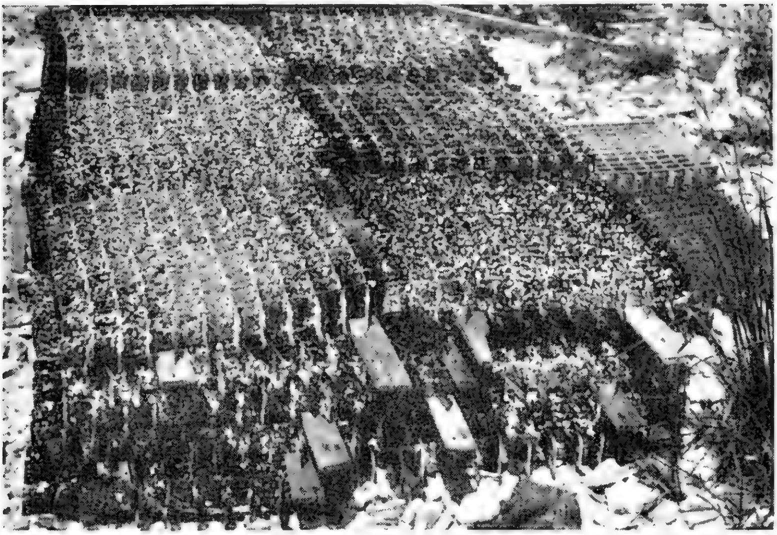
FIG. 26–3. Oyster spat of *Ostrea virginica* growing on a piece of tile. French oyster farmers use tiles similar to that shown above and stack them in large groups on tidal flats.

Connecticut shore of Long Island Sound, oysters frequently acquire a green color from absorption and storage of excess copper. In this case the green coloration is not confined to the gills, but is spread around the mantle. Green oysters of this type have a strong metallic flavor. In Italy the seed is caught on brushes stuck on shallow flats.

Several types of spat collectors were developed in the United States. The most promising among them are the "egg-crate" collectors, made of cardboard coated with a mixture of cement and sand and a small wire bag filled with shells. The American industry so far has not adopted their use, primarily because of the additional cost of material and labor.

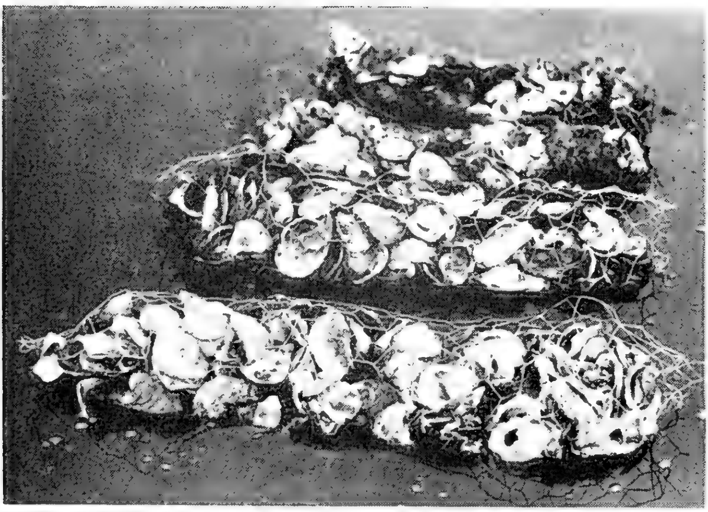
On the Pacific Coast the rapidly growing cultivation of the Pacific oyster (*Ostrea gigas*) depends on the importation of seed from Japan. Attempts made in the State of Washington to obtain seed oysters locally by using the Japanese method of collecting them on garlands of shells suspended from poles placed on tidal flats were only partially successful.

Most of the oysters marketed in Japan are produced by cultivation, which consists in growing oysters in cages suspended from rafts or floats anchored in



(*Courtesy U. S. Fish and Wildlife Service*)

Fig. 26–4. A group of egg crate spat collectors set on tidal flats.



(*Courtesy U. S. Fish and Wildlife Service*)

Fig. 26–5. Wire bag collectors on tidal flats in New England waters.

the harbors and bays. The great advantage of this method is that it makes the oyster grower independent of the character of the bottom.

A simplified form of oyster farming practiced in Delaware Bay, in the lower part of Chesapeake Bay, and in Louisiana waters consists of taking seed oysters from public grounds and planting them on privately leased bottoms. The most valuable seed grounds which support the American industry are located in the upper part of Delaware Bay, in the lower part of the James River, and east of the delta of the Mississippi River in Louisiana. The returns from the planting of seed taken from these grounds rarely reach 4 bushels of adult oysters for 1 bushel of seed. In most cases the yield varies from 0.75 to 2.5 bushels for each bushel planted. Low returns of less than 1:1 are primarily due to the destruction of young oysters by drills, conchs, and other enemies.

Seed-Oyster Industry. Production of seed oysters is a very important and profitable occupation. In 1945 over 2.9 million bushels of seed were sold in the United States, bringing to the oyster growers a total revenue of 1.48 million dollars (Table 120). Probably no less seed was produced by the oyster companies for planting on their own grounds. Chesapeake Bay produces the largest portion of seed sold in the United States. In 1945 the seed from this body of water comprised 89.4 per cent of the total amount purchased by the oyster growers. The average value of the Chesapeake seed was only 34 cents a bushel as compared with the average price of $1.89 a bushel for New England seed. The difference is due to the fact that in Chesapeake Bay the term "seed oysters" applies to all oysters, less than 3 inches long, taken from public oyster grounds. One bushel of James River seed may contain, for instance, several hundred almost fully grown oysters of various ages and sizes, while in New England a bushel of seed may contain several thousands of small oysters of a known age. Potential return from planting a bushel containing large numbers of small oysters is obviously much higher than that from planting a bushel of seed consisting of a smaller number of nearly fully grown oysters. Consequently, the price of New England seed oysters is much greater than that of seed from public reefs.

TABLE 120. PRODUCTION AND VALUE OF SEED OYSTERS IN U. S. A., 1945.

Seed oyster	New England		Middle Atlantic		Chesapeake		Total	
	Bushels	Value	Bushels	Value	Bushels	Value	Bushels	Value
Public	23,612	$26,776	800	$1750	2,642,266	$899,595	2,666,678	$928,121
Private	289,930	549,958	—	—	7,544	2,530	297,474	552,488
Total	313,542	576,734	800	1750	2,649,810	902,125	2,964,152	1,480,609

All figures in thousands of bushels or thousands of dollars.
Source: Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

Public Oyster Grounds. More than a million acres of public oyster reefs or rocks in the United States are open to fishing to those holding licenses sold at a small fee by state departments of fisheries. Through neglect and bad management most of the potentially productive areas have been depleted. In several states the destruction of public grounds was so complete that the oyster industry ceased to exist. In others, as for instance in the Chesapeake Bay states, the productivity of

public grounds has materially declined in spite of the efforts of the state departments of fisheries to prevent the destruction of grounds by planting shells and seed oysters. In many places along the coast the discharge of domestic sewage and industrial wastes destroyed the oyster grounds, or rendered them unsuitable for the production of oysters for food. The production of oysters through cultivation on privately owned or leased grounds, however, remains more or less stable. Although the private grounds comprise only a small fraction of the total acreage of public reefs, 62 per cent of the total catch of oysters in 1945 was derived from them.

Century-old experience in the state maintenance of public reefs shows that self-rehabilitation of grounds without active assistance from man is incompatible with intensive commercial exploitation. The enactment of conservation laws, such as closed seasons, size limit, restriction of gear, etc., has been ineffective in stopping depletion. Likewise, costly efforts of several states to rehabilitate the grounds by planting shells and seed produced no appreciable results. In the absence of a carefully planned system of management and without the control of rate of harvesting, partially rehabilitated grounds became depleted almost as soon as they were opened to fishing. Experience in introducing a system of state management of principal public reefs in Maryland, carried out with the cooperation of the United States Fish and Wildlife Service, has shown that at present 1 acre of depleted oyster ground can be rehabilitated for about $150.00. Thus, the rehabilitation of a substantial portion of some 180,000 acres of public bars in Maryland alone would require an expenditure of several million dollars of taxpayers' money. The obvious alternative is to permit the leasing of depleted public reefs to private growers and to concentrate the state efforts on the maintenance and development of seed-oyster grounds from which young oysters could be supplied to planters.

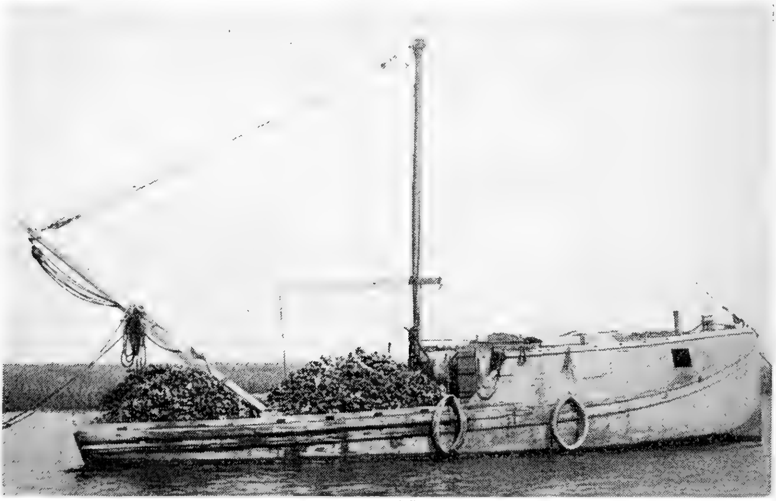
Harvesting. Oysters are harvested by grabs, tongs, patent tongs, dredges, and mechanical harvesters. Hand-picking by grabs is practiced in some southern states where oysters are taken from tidal flats exposed at low water. Tonging is adapted to shoal waters and is profitable only on grounds where oysters are plentiful. On the good grounds of Chesapeake Bay a tonger averages 20 to 35 bushels a day.

Dredges vary in their capacity of from 5 to 25 bushels. They are operated from schooners, motor boats, and steamers. Some of the larger steamers in Long Island Sound are equipped with 6 dredges (3 on each side), capable of harvesting at the rate of 1,400 bushels an hour. In several states no power dredges are permitted on public reefs, but dredging with sail boats is allowed and power-driven hoisting engines can be used for hauling up the gear.

Mechanical harvesters represent the most recent development in the technique of oyster dredging. At present there are two distinct types: the suction dredge, which works on the principle of a vacuum cleaner, and the scooper. In one of the largest harvesters of the first type, which operates in Long Island Sound, suction is produced by a powerful jet of water directed into one leg of a Y-shaped eductor. The other leg of the eductor is actually the outboard suction unit. Oysters taken through this part are delivered by a strong stream of water to a conveyor located on the deck. The largest harvester of this type, in operation since March 1948, is 95 feet long, 30 feet beam, and 8 feet deep. Its hold has a capacity of 10,000 bushels.

(Courtesy U. S. Fish and Wildlife Service)

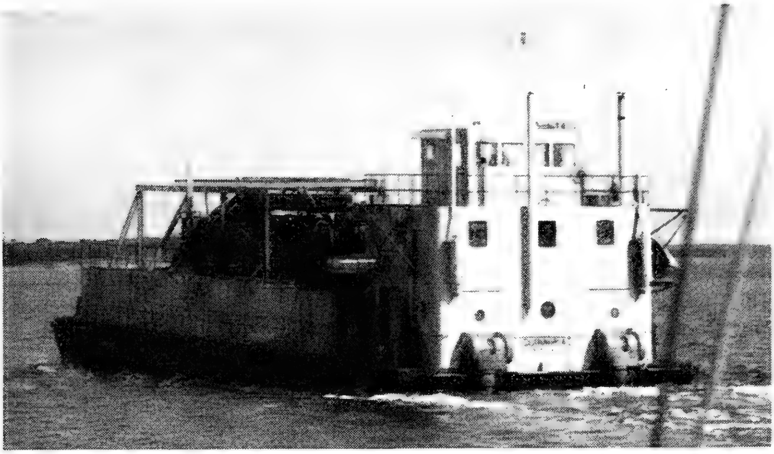
FIG. 26–6. Tongers working in southern waters.



(Courtesy U. S. Fish and Wildlife Service)

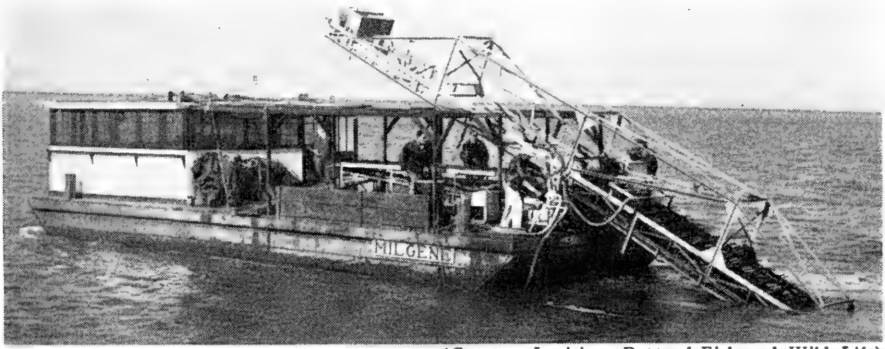
FIG. 26–7. Heavily loaded oyster dredger in South Carolina returning home.

The scooper type of harvester, developed by J. Jurisich of Louisiana, consists of a rakelike dredge with steel teeth. The dredge rests on runners, one on each side, which prevent excessively deep digging. The gear is lowered to the bottom by means of a strong cantilever mounted on a suitable stand on the deck of a barge. An endless chain type of conveyor, with flexible loops made of steel cable, is mounted on the cantilever in such a way that when the harvester is in operation oysters and other material caught by the rake are scooped by flexible loops and brought up on deck. The entire structure is so well balanced that the rake rests very lightly on the bottom and the whole unit is easily bounced if it runs into a



(Courtesy U. S. Fish and Wildlife Service)

FIG. 26–8. "Quinnipiac" suction dredger in Long Island Sound.



(Courtesy Louisiana Dept. of Fish and Wild Life)

FIG. 26–9. Oyster harvester of a scooper type in Louisiana.

rock or similar obstruction. The efficiency of both harvesters is so high that they should not be used on public reefs, which in a short time could be completely stripped by this method of fishing. Harvesters can be used to a great advantage, however, in the cultivation and replanting of large areas of bottoms by private companies or state organizations.

Natural Enemies of the Oyster

Man is undoubtedly the greatest enemy of the oyster. Through his greediness, neglect, and lack of foresight he is directly responsible for the devastation of huge areas of natural oyster bottoms. In his destructive actions he is being helped by the natural enemies which prey on defenseless oysters. Various marine snails, usually called drills or conchs, are particularly harmful. They attack the oyster by boring a small hole in its shell into which they insert their long proboscis equipped

with a rasplike structure, called a radula; by rapid movements of the radula small pieces of oyster meat are scraped and devoured.

The common oyster drill or screw-borer of the Atlantic Coast (*Urosalpinx cinerea* Say) and the conch (*Thais haemastoma floridana* Conrad) of the Gulf States cause very heavy damages, especially to young oysters. There are several places along the coast of the United States where oyster spat has no chance to reach maturity, for it is usually destroyed by drills or conchs within a year. For example, oyster grounds in lower Chesapeake Bay are so heavily infested with screw-borer that

FIG. 26–10. Tangle used for catching starfish in Long Island Sound.

the oyster growers have to be satisfied with a return of ½ bushel of market oysters to 1 bushel of seed planted. A yield of 1 to 2.5 would have been easily realized if these grounds were free of drills.

Oystermen themselves help to spread the drills and conchs to noninfested areas by transplanting their stock without taking any steps to clear it of snails or their eggs, encapsulated in the gelatinous egg cases attached to the shells. In this way the drills, which themselves can crawl only over short distances, have spread over the entire coastline and have even been introduced to Europe. Through the importation of Japanese seed oysters to the Pacific Coast, a very destructive Japanese conch (*Tritonalia japonica* Dunker) was introduced to Puget Sound waters, where it established itself and became a menace to the oyster fishery.

Control of marine snails is expensive and difficult. The present methods of

control of *Urosalpinx* consist of trapping or dredging with a special drill dredge (Galtsoff *et al.*, 1937). No method of controlling *Tritonalia* has yet been developed, except that of burning with flame torches the egg cases laid on submerged structures exposed at low water.

The No. 2 oyster enemy is the starfish (*Asterias forbesi* Desor), which inflicts heavy damages to oysters in Narragansett Bay and Long Island Sound. Two methods of control are available: mopping the grounds with tangles and sprinkling the infested areas with finely powdered unslacked lime (Loosanoff and Engle, 1942). Control of individual grounds is, however, ineffective and expensive because the nearby areas remain unattended (Galtsoff *et al.*, 1939). In Long Island Sound and Narragansett Bay the centers of infestation from which the starfish spread to adjacent bottoms are abandoned private grounds and depleted public reefs. Starfish larvae swim freely and are carried by tides and currents over a large area. Efforts of the United States Fish and Wildlife Service to persuade the oyster growers to join forces and attack the centers of starfish population rather than to attempt to control them on their individual lots so far have been fruitless.

Of the other enemies of lesser importance mention should be made of the boring sponge (*Cliona*) and boring clam (*Martesia*), which attack the shell of the oyster, the drumfish (*Pogonias*), and various species of skates (*Raja*), which feed on mollusks and occasionally destroy large numbers of oysters. Many sedentary organisms that attach to the shell of the oyster, such as mussels (*Mytilus*), slipper shells (*Crepidula*), barnacles (*Balanus, Chtamulus*), and many others occasionally become very troublesome. The slipper shell (*Crepidula*), introduced with the eastern oyster to the Pacific Coast and to Europe, causes much more serious trouble by overcrowding planted oyster grounds in the new environment than in its original habitat. Experience with the introduction of various foreign species of animals and plants teaches that the dangers of bringing with them undesirable pests or disease-producing bacteria are almost inevitable. These difficulties and dangers should be carefully considered before any new form is brought in.

Preparation for Marketing Oysters

Upon reaching the wharf the oysters carried in a hold or on the deck of an oyster boat are unloaded by means of bucket and hoist, or are delivered to the plant in large steel wheelbarrows. Many oyster houses use elaborate systems of conveyors which take the oysters from the deck, raise them into the upper story, and distribute them to the shucking benches or the packing rooms. Some of the large oyster companies in the northern states carefully wash the mud off the oysters, and then place them for 24 hours in running sea water to which free chlorine gas is added in a concentration sufficient to sterilize the shells. Large concrete tanks, about 3 feet deep, are used for this purpose. They have false bottoms consisting of wooden grids to remove debris and materials discharged by the oysters. It is claimed that washing and chlorination provide additional safeguards against contamination of shellfish and improve their shipping quality.

In Europe oysters taken from growing grounds are very carefully washed, sorted, and packed for shipment in small baskets or similar containers. Great attention is being paid by French oyster dealers to the cleanliness and good appearance of the shell of the oyster as well as to the flavor of its meat.

Less than 10 per cent of all the oysters produced in the United States are sold in shells. After being washed and conditioned, the oysters are sorted according to different grades, packed in barrels, and shipped to their destinations. Even during fairly warm weather shipping of oysters in shells requires no icing.

(Courtesy U. S. Fish and Wildlife Service)

Fig. 26–11. Removable conveyor for unloading oysters.

Commercial Brands

Atlantic and Gulf states' oysters (*O. virginica*) are usually sold under various trade names, such as Bluepoint, Chincoteague, Maurice Cove, Cotuit, Lynnhaven, and so on, which refer to the name of the bay or harbor in which they are produced or to the name of the nearest town. Thus, the popular brand "Bluepoint" refers to oysters planted and cultivated in the waters of Great South Bay on Long Island. The New York State Legislature recognized the popularity of this brand by enacting a law (Section 320, Conservation Laws, New York State) which states that no person, firm, or corporation shall sell or offer for sale under the name of "Bluepoint" any oysters other than those which have been planted for at least 3 months in the waters of Great South Bay. According to the Regulations of the U. S. Department of Agriculture "the use of a geographical name shall not be permitted in connection with food and drug products not manufactured or produced in that place, when such name indicates that the article was manufactured or produced in that place" (Reg. 298, U. S. Dept. of Agriculture, Bureau of Chemistry, 1918). In practice, and especially in selling live oysters for half-shell trade, the restriction imposed by this regulation is disregarded and the brands under which some of the oysters are sold refer rather to their size than to the place of origin or cultivation. Thus, any small oysters are frequently called "Bluepoints," although they may come from Chesapeake Bay, the Carolinas, or elsewhere. Likewise, the name "Lynnhaven" is frequently given to oysters of large size and slightly elongated shape. Small native oysters of the Pacific Coast (*O. lu-*

rida) are usually sold under the name "Olympia," and the Japanese oyster (*O. gigas*), grown on the West coast, is generally called "Pacific."

Shucking

The principal business in the United States is in raw, shucked oysters (i.e., in oyster meat removed from the shell). Shucking requires great skill. Shuckers work at benches using specially designed knives, the shape and size of which vary in different states. The knife is thrust between the shells at the side of the thin end and the oyster, held in the left hand, is slightly turned around a sharp edge of the knife to cut the large adductor muscle. Another cut across the same muscle on the opposite side of the body removes the oyster, and the meat is thrown in a measuring can containing a small amount of water. Some shuckers prefer to crack the ends or "bills" of the shell before inserting the knife. A good shucker averages 10 to 12 gallons a day although this amount may be considerably exceeded by a very proficient worker. "Fat" oysters yield about 6 quarts of meats per bushel.

Several patents have been issued to inventors of mechanical shucking machines. The latter can be divided into two types: in the first the separation of shells is accomplished by the shearing action of a chisel-like cutter, which by means of a hand lever is thrust into the oyster placed under it in a vertical position; the second type utilizes the principle of a potato peeler. Oysters are placed on a grinding wheel rotating in horizontal position. By shaking and grinding the shells open and the meat is removed in the conventional manner with an oyster knife.

Oyster meats removed from shells are placed by the shucker in a metal container of a capacity of 1 quart, partially filled with water. When the container is full, it is taken to the measuring window where the shucker receives a "credit" either by a ticket or token. Containers are emptied on a washing or skimming table covered with Monel metal or other noncorrosive material, and the meats are drained. In some plants oyster meats are passed over inclined Monel metal riffle boards in a cascade of fresh waters. At this time all discolored meats, shells, and oyster crabs are removed. From the skimming tables the meats are forced by water into washing tanks, where they are stirred with a paddle before being put into the blowing tank. The most common practice is to wash and blow in the same tank, the meats being held in the tank of water until enough have accumulated for blowing. The blowing tank is usually made of corrosion-resistant metal. It measures 3 to 4 feet in diameter and has a conical-shaped bottom, with a valve at the lowest point for draining the water. The tank is provided with a removable, perforated false bottom, below which runs a perforated pipe. Violent agitation of water and oyster meats by air forced through the pipe enhances the efficiency of washing and improves the appearance of oyster meats; but at the same time it causes great loss of mineral salts and of natural oyster liquor. The length of blowing time varies from 3 to 10 or even 15 minutes. A 3-minute limit is used in most states since excessive blowing may lead to the adulteration of the oysters prohibited by the regulations of the Pure Food and Drug Administration. After blowing, the oysters are drained on skimming tables before being packed.

After washing, oyster meats are sorted according to the established grades (Food and Drug Adm., No. 2, Rev. 1, 1949, 36.10–36.22) and packed in large cans varying from 1- to 5-gallons capacity, or in small individual containers of 1-pint

capacity. The containers are not returnable. To safeguard the public against contamination and adulteration the Food and Drug Administration and the U. S. Public Health Service enforce a number of regulations which prescribe recommended practices of shucking, storage, and shipment of oysters. The oysters

(Courtesy Bluepoints Co., Inc.)

Fig. 26–12. Washing shucked oysters.

(*O. virginica*) are graded according to their size: Extra large, counts or plants: 160 oysters to the gallon, or not more than 44 of the smallest selected from the sample in a quart; Large or extra selects: more than 160 but not more than 210 oysters per gallon, or not more than 58 of the smallest per quart; Medium or selects: more than 210 but not more than 300 oysters per gallon or not more than 83 smallest oysters per quart; Small or standards: more than 300 but not more than 500 oysters per gallon, or not more than 138 smallest oysters per quart; Very small: more than 500 oysters per gallon and more than 112 largest oysters per quart. Pacific oysters are graded according to their number per pint: 5 to 8, 8 to 10, 10 to 12, 12 to 15, 15 to 18, and over 18 oysters per pint.

Freezing

The freezing of oysters is a relatively new process which is gradually gaining popularity. At present several plants in New England and the Chesapeake Bay states prepare frozen oysters for the market.

After the oysters have been shucked and washed, as described above, the oyster

meats are drained free from water and dumped into a grading machine which separates them into four established sizes: Small Selects, Selects, Extra Selects, and Counts. The machine grades the meat at the approximate rate of 100 oysters per minute.

The meats are then placed in Monel metal cans and transferred to a filling room where they are packed into 12-ounce rectangular, cold-waxed cartons, lined with moisture-proof cellophane sheets. The carton contains from 18 to 20 Select oysters, which is the most popular grade for freezing. The weight is checked, the cartons are closed, then wrapped, and heat-sealed in waxed glassine paper. The packages are placed on trays and put in a freezer for about 1½ hours. The "Birdseye" multiplate freezer (for description see Tressler and Evers, 1947, p. 81) is used by the Bluepoint Company plant in Greenport, Long Island, in which large quantities of oysters are frozen. After removal from the freezer the cartons with frozen oysters are packed in corrugated fiberboard shipping containers and stored at about 0° F.

Freezing is also being used by the packers of the Pacific oyster in the state of Washington. The method is similar to that employed on the Atlantic Coast. The oyster meats are placed in waxed paperboard cups which are put on trays and pushed into a freezing room where the oysters are frozen in a blast of air at − 25° F.

Canning

Oyster canning is an old industry in the United States. It started in 1820 in Baltimore, Maryland as a means of overcoming the difficulties in transportation and storage. It provided an excellent method of extending the market and made the name "Cove Oysters," as the canned product at that time was labeled, known throughout the world. In 1948 the pack of canned oysters in the United States was 357,000 standard cases, valued at 4.8 million dollars. As can be seen from Table 121 Louisiana contributed the largest portion of the pack, Mississippi occupying the next place. The formerly prosperous oyster-canning industry of Maryland ceased to exist primarily because of the decline in the catch of oysters in Chesapeake Bay.

TABLE 121. PACK OF CANNED OYSTERS IN THE UNITED STATES, 1948.

States	Standard cases	Value
N. Carolina, S. Carolina and Alabama	73,196	$ 838,699
Mississippi	85,673	1,157,740
Louisiana	114,722	1,486,177
Washington and Oregon	83,489	1,294,915
Total	357,080	4,777,531

Note: Standard cases represent the various sized cases converted to the equivalent of 48 cans to the case, each can containing 4⅝ ounces drained weight of oyster meats.
Source: U. S. Fish and Wildlife Service, *Annual Summary* (1948).

There are two methods of canning oysters, one used in the South Atlantic and Gulf States and the other on the Pacific Coast. The canneries of the Atlantic and

Gulf Coasts use wild-grown oysters harvested from public reefs. The stock delivered to canneries frequently contains a large proportion of undersized and young oysters. Without washing the shells they are unloaded directly into the steaming cars, which have a capacity of 5½ barrels (22 bushels) each. The loaded cars are run into a steam box with doors at each end, and are steamed from 10 to 15 minutes at 245° F (118.30° C) (12-pounds pressure). The technique, however, varies somewhat in different plants, and the steaming time may be only from 6 to 10 minutes at 250° F (121° C) (15-pounds pressure), not including the "come-up" and "blow-down" times, which are usually from 6 to 8 minutes and 1 minute, respectively. Under steaming the shells of the oysters open and lose a great portion of their juice. The cars are then rolled into a shucking room and the meat is removed while hot. After being dropped into a galvanized flume the meats are forced by a stream of cold water to the washing tanks where a considerable quantity of grit and shell particles is washed and trapped by baffles. Washing continues from 20 to 30 minutes; then the meats are transferred by dip nets to screen-bottomed trays, in which they are left to drain for 20 minutes. After inspecting and grading, the meats are packed in cans and weighed. The filled cans are conveyed to the sealing machine where hot 1 per cent brine is added and the cans are sealed. Time of processing depends on the size of the can. Five-ounce cans are usually processed for 17 minutes at 240° F (115.6° C), others for 19 minutes at 240.5° F (115.6° C), or for 10 minutes at 250° F (121° C).

Pacific oysters used in canning are grown from imported Japanese seed planted on privately owned bottoms. They are either picked at low tide or dredged and loaded on scows which at high water are towed to the cannery. At the wharf the oysters are shoveled into an elevator consisting of a watertight trough mounted on an endless chain. A spray of water at a pressure of about 50 pounds psi is used to wash the mud from the oysters as they go up. The oysters are then placed on cars of about 8-bushels capacity each; these are pushed along the slightly inclined track to a cylindrical steam chest of heavy construction with doors at each end. Time and temperature of precooking vary from 3½ to 6 minutes at 240.5° F (115.6° C) (10-pounds pressure) and from 10 to 15 minutes at 212° F (100° C) (atmospheric pressure).

The oysters are shucked into 3-gallon buckets containing 1 gallon of water or 2 to 3 per cent brine.

Some canneries prefer to use a continuous precooker which consists of a seat conveyor enclosed by an insulated iron housing. The precooker may be 75 feet long; the average time required for precooking is 7½ minutes, but the speed of the progress of oysters through the precooker may be regulated. Moist steam is delivered from perforated pipes which extend the full length of the cooker both above and below. The maximum temperature reached by this arrangement does not exceed 210° F (98.9° C). It is claimed that the continuous process has certain advantages, for it requires less labor and less plant space. There is also less shrinkage of oyster meat.

Precooked oysters are removed with a knife and placed for washing in a metal tank equipped with a perforated false bottom. After thorough washing, aided by aeration or blowing, the shucked oysters are emptied on a conveyor and sorted in four grade sizes: large, medium, small, and cuts, the last grade comprising damaged oysters.

The packers fill the cans, weigh them, and insert an extra oyster to insure against excessive shrinkage in processing. After exhausting and sealing, the cans are processed at 240.5° F (115.6° C). The time of processing varies from 20 to 42 minutes depending on the size of the cans (Jarvis, 1943).

Pacific Coast canners use elaborate methods of growing and processing their product, but are fully recompensed for their extra efforts by the high quality of their product.

In 1948 oysters were canned in 48 plants, of which 2 were located in North Carolina, 3 in South Carolina, 13 in Mississippi, 18 in Louisiana, 10 in Washington, and 1 each in Alabama and Oregon.

Besides canned oysters the Pacific Coast oyster industry in 1948 packed 1,037 standard cases of smoked oysters, valued at $82,452.

Sanitary Control

Sanitary supervision of the industry in the United States is exercised by the U. S. Public Health Service, U. S. Food and Drug Administration, and State Health Departments. Its purpose is to prevent the production and consumption of infected or adulterated oysters which may endanger human health. Strict compliance with the administrative measures is vital to the industry because of extensive pollution of waters in the vicinity of large cities and the danger of obtaining shellfish unfit for human consumption. Bacteriological examination of shellfish was the subject of extensive studies conducted in the United States and abroad. The present system guarantees that shellfish obtained from a legitimate grower or dealer are free of pathogenic germs and are safe to eat. Present methods of control rely primarily on sanitary and bacteriological examination of oyster grounds, using *Escherichia coli* as an index of pollution of water. Bacteriological examination of shellfish meat presents many technical difficulties and is less reliable than the examination of water in which the oysters live and which they filter for feeding. Oyster grounds and shore plants found to be satisfactory from a sanitary point of view are certified by a state health officer. All state certificates are approved by the U. S. Public Health Service. On the basis of the compliance by state health authorities with the sanitary standards recommended by U. S. Public Health Service for the guidance of the industry and interstate shipping companies this Service issues at frequent intervals the list of certified dealers and the numbers of their licenses.

Each shipment must be accompanied by a tag giving the number of the certificate and the name and address of the dealer. Shipment of oysters not accompanied by such certificate is prohibited. Sanitary requirements for shucking houses and canneries cover all phases of processing oysters. The most important requirements are: periodical medical examination of the personnel engaged in opening and processing of oysters; disinfection of utensils; general cleanliness of oyster houses; methods of shucking and processing of oysters; and many others. Full description of the present elaborate methods of sanitary control of shellfish can be found in a publication of the U. S. Public Health Service, entitled "Manual of Recommended Practice for Sanitary Control of Shellfish Industry" (1946). Under the present system of control the customer making his purchase from a legitimate dealer should have no fear of obtaining contaminated shellfish.

Sanitary precautions similar to those enforced in the United States are used in European countries. Artificial purification of shellfish by chlorination is practiced in England. Before World War II France used a unique method of purifying oysters by keeping them in sea water filtered through stone filters. Large purification tanks of that type were in operation in Marseilles harbor.

The "R" Rule

Common belief that oysters should not be eaten in the months whose names do not contain the letter "r" is not based on fact. Oysters can be eaten, and are being eaten, at any time of year. Being highly perishable, their transportation and storage during the warm season present difficulties and require additional care. Furthermore, summer is the time when in many places oysters spawn. After the discharge of their sex products they become watery, and contain but little solid meat. As a rule, at this time they lack flavor and consistency, which develop with the onset of cold weather. There are, however, several localities in various states where oysters of fairly good quality are available throughout the year.

Chemical Composition and Nutritional Value

The chemical composition of oyster meat is not constant, but varies over a wide range depending on the quality of the oysters, the location from which they are taken, the concentration of salts in the sea water, and the season. These facts should be remembered in discussing the chemical composition of an "average" oyster. Many analyses of oysters made in various parts of the world on different species of oysters have been published. In most cases they were made for specific purposes. However, from a few detailed analyses now available it is evident that the solid fraction of meat of various species of oysters is high in nitrogen and phosphorus-containing compounds. Both water-soluble and water-insoluble proteins are present and carbohydrates, primarily in the form of glycogen, are found in quantities varying from a fraction of 1 to 8 per cent of the wet weight. The fatty bodies, usually reported as "ether extract," are present in relatively small concentrations of about 1 to 1.6 per cent of fresh meat. The content of mineral salts (ash) varies from about 0.5 to 2.76 per cent; it consists primarily of NaCl, but contains also almost every chemical element present in sea water. Qualitative spectrographic analysis of 22 samples of oyster ash, made by the U. S. Bureau of Mines at the request of the U. S. Fish and Wildlife Service, showed that the bulk of the samples contained Na, K, Ca, Mg, and P, and that the following elements were present in low concentrations: Cu, Fe, Si, Al, Sr, Li, Rd, Ni, Ag, Ti, Zn, V, Pt, Mn, Au, and Zr.

Oysters have the ability to accumulate in their tissues iron, copper, zinc, manganese, and probably other heavy metals. The role of these metals in the physiology of the oyster is not known. Probably some of the metals are stored in the tissues and are not actively involved in any physiological function. The problem so far has been little studied. Observations conducted in the United States show that excessive accumulation of copper produces green discoloration in *O. virginica* (Galtsoff and Whipple, 1931) and that copper content in the tissues of the oyster is the highest in the northern states (Rhode Island, Connecticut) and lowest in the waters of South Carolina and Florida. The iron content follows the opposite

course: it is higher in the oysters of the South Atlantic states and lower in northern oysters. During periods of sexual maturity the manganese content of oyster tissues significantly increases. The metal is stored primarily in the ovaries and is apparently associated with the female sexual cycle (Galtsoff, 1942).

Chemical composition of British and New Zealand oysters does not differ significantly from that of the American oyster (Table 122).

TABLE 122. CHEMICAL COMPOSITION OF MEAT OF ATLANTIC COAST OYSTER (*Ostrea virginica*), BRITISH OYSTER (*Ostrea edulis*) AND NEW ZEALAND OYSTER (*O. commercialis*).

	Atlantic oyster	British oyster	New Zealand oyster
	%	%	%
Water	86.0	76.84	75.2 –78.8
Dry matter	13.1		
Protein	6.2	11.18	12.20–13.72
Fat	1.2	1.97	1.83– 3.66
Carbohydrates	3.7	8.00	
Glycogen		7.58	0.5 – 3.74
Sodium chloride		0.22	
Other mineral substances		1.64	
Ash	2.0	2.02	

Source: Ranson, G., "The Life of the Oyster," Paris, Gallimard, 1943.

As in the American oyster the chemical composition of the European oyster (*O. edulis*) does not remain constant, as can be seen from the observation on oysters grown in Norway (Table 123).

TABLE 123. ANNUAL CHANGES IN THE CHEMICAL COMPOSITION OF *Ostrea edulis* IN NORWAY

	Average weight	Water	Glycogen	Carbohydrates	Fat	Protein	Ash
	g	%	%	%	%	%	%
Maximum	14.63	81.9	7.95	9.56	2.52	11.22	1.48
Minimum	7.60	76.0	5.15	6.34	1.56	8.77	1.24
Average for 1936	11.30	78.65	6.76	7.77	2.17	10.06	1.34

Source: Gaarder, T., and Alvasker, E., "Biology and Chemistry of the Oyster in Norwegian Waters," *Bergen Museum Yearbook* (1941).

Among the organic constituents of the oyster meat mention should be made of the presence of the glycerophosphoric acid, stigmasterol, and ostreasterol, discovered in 1934 in *Ostrea virginica* by Bergmann (1934).

From the nutritional point of view oysters present many advantages because of their digestibility and the presence of minerals and vitamins necessary to maintain health. Determinations made by the United States Fish and Wildlife Service

show that a single portion consisting of 6 raw Atlantic oysters, weighing approximately 3½ ounces, contains the following nutrient factors:

Protein	6.5	g	Thiamine	0.18	mg
Fat	1.6	"	Riboflavin	0.22	"
Glycogen	4.2	"	Nicotinic acid	1.2	"
Calcium	58	mg	Ascorbic acid	3	"
Phosphorus	112	"	Inositol	44	"
Iron	6.1	"	Folic acid	0.25	"
Copper	3.7	"	Pyridoxine	33	micrograms
Iodine	0.05	"	Biotin	9	"
Vitamin A	375	int. units	Calories	60	
Vitamin D	5	" "			

According to these data one serving of raw oysters will supply more than the daily allowance of iron and copper, about one-half of the iodine needed, and about one-tenth of the daily requirement of protein, calcium, phosphorus, vitamin A, thiamine, riboflavin, and nicotinic acid (Radcliffe, 1947).

By-products

Oyster shells from shucking houses are used for road construction and for manufacture of poultry food, and are burned for lime. During World War II the newly developed plants for the extraction of magnesium from sea water used very large quantities of oyster shell as a source of lime needed for the precipitation of magnesium hydroxide (Chap. 4).

In 1948 the United States produced 345,075 tons of oyster and marine clam shell products, valued at $2,474,492. The shells to be used for poultry "grit" are first dried in a heated rotary drier, then crushed, screened to various sizes, and packed in bags.

Large quantities of so-called mud shell (i.e., shells of dead oysters buried in mud) are dredged from Texas waters and are used by the manufacturers of lime and poultry foods. The demand for oyster shells is so great that oyster growers frequently experience difficulty in obtaining the cultch they need for planting on their grounds; thus, lack of shells in some of the Atlantic States constitutes a serious handicap to the progress of the oyster industry. Because of the inadequate supply of shells for planting attempts were made to use different substitutes. The most promising is probably the slag from steel plants. Experiments carried out in Delaware Bay and in Maryland waters showed that slag may be used instead of shells to catch seed oysters. It presents, however, several disadvantages due to its weight, shape, and other characteristics. So far the oyster shells remain the most practical material to be used in the cultivation of oysters.

REFERENCES

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

Awati, P. R., and Rai, H. S., "*Ostrea cucullata* (the Bombay Oyster)," Lucknow, India, *The Indian Zoological Memoirs III* (1931).

Bergmann, W., "Contributions to the Study of Marine Products. III: The Chemistry of Ostreasterol," *J. Biol. Chem.*, **104**, 553–557 (1934).

Brooks, W. K., "The Oyster," Baltimore, Johns Hopkins Press, 1905.

Chipman, W. A., and Galtsoff, P. S., "Effects of Oil Mixed with Carbonized Sand on Aquatic Animals," U. S. Fish and Wildlife Service, *Special Scientific Report, Fishery*, **1** (1949).

Federighi, H., "Studies on the Oyster Drill (*Urosalpinx cinerea* Say)," U. S. Bureau of Fisheries *Bull.*, **47**, 85–115 (1931).

Food and Agricultural Organization of the United Nations, Washington, D. C., "Yearbook of Fisheries Statistics, 1947," 1948.

Gaarder, T., and Alvasker, E., "Biology and Chemistry of the Oyster in Norwegian Waters," Naturvitenskapelig Rekke, *Bergen Museum Yearbook for 1941*, **6** (1941).

Galtsoff, P. S., "The Biochemistry of the Invertebrates of the Sea," *Ecological Monographs*, **4**, 481–490 (1934).

Galtsoff, P. S., "Physiology of Reproduction of *Ostrea virginica*, I, II, III," *Biol. Bull.*, **74**, 461–485, *Ibid.*, **75**, 286–307, and *Ibid.*, **78**, 117–135 (1938, 1940).

Galtsoff, P. S., "Accumulation of Manganese and the Sexual Cycle in *Ostrea virginica*," *Physiological Zoology*, **15**, 210–215 (1942).

Galtsoff, P. S., "Reaction of Oysters to Chlorination," U. S. Fish and Wildlife Service, *Research Rept.*, **11** (1946).

Galtsoff, P. S., Chipman, W. A., Jr., Engle, J. B., and Calderwood, H. N., "Ecological and Physiological Studies of the Effect of Sulfate Pulp Mill Wastes on Oysters in the York River, Virginia," U. S. Fish and Wildlife Service, *Bull.*, **43**, 58–186 (1947).

Galtsoff, P. S., and Loosanoff, V. L., "Natural History and Method of Controlling the Starfish (*Asterias forbesi* Desor)," U. S. Bureau of Fisheries *Bull.*, **49**, 75–132 (1939).

Galtsoff, P. S., Prytherch, H. F., and Engle, J. B., "Natural History and Methods of Controlling the Common Oyster Drills (*Urosalpinx cinerea* Say and *Eupleura candata* Say)," U. S. Bureau of Fisheries, *Fishery Circular*, **25** (1937).

Galtsoff, P. S., and Whipple, D. V., "Oxygen Consumption of Normal and Green Oysters," U. S. Bureau of Fisheries *Bull.*, **46**, 489–508 (1931).

Hopkins, A. E., "Experimental Observations on Spawning, Larval Development, and Setting in the Olympia Oyster, *Ostrea lurida*," U. S. Bureau of Fisheries *Bull.*, **48**, 439–503 (1937).

Hunter, A. C., and Harrison, C. W., "Bacteriology and Chemistry of Oysters, with Special Reference to Regulatory Control of Production, Handling and Shipment," U. S. Dept. Agr., *Tech. Bull.*, **64** (1928).

Jarvis, N. D., "Principles and Methods in the Canning of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.*, **7** (1943).

Loosanoff, V. L., and Engle, J. B., "Spawning and Setting of Oysters in Long Island Sound in 1937, and Discussion of the Method for Predicting the Intensity and Time of Oyster Setting," U. S. Bureau of Fisheries *Bull.*, **49**, 217–255 (1940).

Loosanoff, V. L., and Engle, J. B., "Use of Lime in Controlling Starfish," U. S. Fish and Wildlife Service, *Research Rept.*, **2** (1942).

Nelson, T. C., Reports of the Department of Biology of the New Jersey Agricultural College Experiment Station for the years 1916–1930, Trenton, N. J., 1917–1930.

Orton, J. H., "Oyster Biology and Oyster Culture," London, Edward Arnold and Co., 1937.

Raas, T. S., "World Fisheries" (in Russian), Moscow, 1948.

Ranson, G., "The Life of the Oyster," Paris, Gallimard, 1943.

Roughley, T. C., "The Life History of the Australian Oyster (*Ostrea commercialis*)," *Proc. Linnaean Society New South Wales*, **43**, 279–333 (1933).

Tressler, D. K., and Evers, C. F., "The Freezing Preservation of Foods," 2nd Ed. New York, Avi Publishing Co., 1947.

U. S. Food and Drug Administration, "Definitions and Standards for Food," *Service and Regulatory Announcements, Food, Drug and Cosmetic Adm.*, **2**, Rev. 1, 56–58 (1948).

U. S. Public Health Service, "Manual of Recommended Practice for Sanitary Control of the Shellfish Industry," *Public Health Bulletin*, **295** (1946).

CHAPTER 27

The Clam Industry of the United States

Introduction

Of all the shellfish of United States coastal waters clams are one of the most popular. The variety of clam products, available in nearly all sections of the United States, and the delicate "tangy" clam flavor are almost universally enjoyed by the consuming public. This salt-water bi-valve is available in a variety of forms as "clam nectar," "clam broth," "minced clams," "clam chowder," and frozen and fresh clams, all of which have served to popularize it even in those areas far removed from points of production. In the areas where clam flats are common it is even more popular because the amateur can dig them fresh each day.

There are few who have visited New England seaside resorts who have not experienced the delights of the "clam bake," where corn, potatoes, and other sea foods are often roasted together with clams in a hole lined with hot stones and covered with fresh seaweed. The clam bake in this section of the country may be compared with the barbecue in the interior areas.

Commercial Importance

Although clams have long been recognized as articles of food, only in recent years have they been highly esteemed. In the United States clams are eaten chiefly by inhabitants of the Atlantic Coastal states. Recently clams have become popular as a food on the Pacific Coast, and an important industry has been developed in that region. Small hard clams, called "littlenecks," have become very popular in New England and are eaten both raw and steamed in the shell, as well as fried in deep fat. Comparatively small quantities of fresh clams are shipped from the Atlantic Coast to inland cities.

Maine and Massachusetts possess the most important clam fisheries, and each produces over 5½ million pounds a year. Other states which have important clam fisheries are Rhode Island, Connecticut, New York, North Carolina, and Washington. New England produces soft clams chiefly. South of New York the hard clam is the only commercial clam of importance. The razor clam is the most important clam in Washington and Oregon. The annual production of canned clams almost equals in value the total quantity of clams marketed fresh. The latest available statistics on the clam industry of the United States are presented in Tables 124, 125, and 126 (pp. 576–577).

Species Commercially Utilized

Two important species of clams are found on the Atlantic Coast of North America: *Mya arenaria,* the soft clam; and *Venus mercenaria,* the hard clam or quahog. The large surf clam (*Mactra solidissima*) was formerly used as bait and

TABLE 124. PRODUCTION OF CLAMS IN THE UNITED STATES AND ALASKA, 1947.
(Expressed in thousands of pounds and thousands of dollars)

Area	Cockle		Coquina		Hard		Ocean quahog		Pismo	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
New England	—	—	—	—	5,260	1,471	311	20	—	—
Middle Atlantic	—	—	—	—	13,566	4,566	—	—	—	—
Chesapeake Bay	—	—	—	—	1,128	564	—	—	—	—
South Atlantic and Gulf [1]	—	—	54	14	1,194	325	—	—	—	—
Pacific Coast	—	—	—	—	309	94	—	—	15	8
Alaska	5	[2]	—	—	11	1	—	—	—	—
Total	5	[2]	54	14	21,468	7,021	311	20	15	8

Area	Razor		Soft		Surf		Mixed		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
New England	32	5	8,810	1,847	214	58	—	—	14,627	3,401
Middle Atlantic	[2]	[2]	1,982	385	3,484	366	—	—	19,032	5,317
Chesapeake Bay	—	—	6	1	—	—	—	—	1,134	565
South Atlantic and Gulf [1]	—	—	—	—	—	—	—	—	1,248	339
Pacific Coast	910	359	7	1	—	—	46	12	1,287	474
Alaska	607	58	—	—	—	—	—	—	623	59
Total	1,549	422	10,805	2,234	3,698	424	46	12	37,951	10,155

[1] Data are for 1945.
[2] Less than 500 pounds and 500 dollars.
Note: The quantities shown represent the weight of clam meats harvested exclusive of the shell.
Source: U. S. Fish and Wildlife Service.

TABLE 125. UNITED STATES PACK OF CANNED CLAMS AND CLAM PRODUCTS, 1948.

The 1948 pack of canned clams and clam products amounted to 1,179,774 cases, valued at $8,329,639 to the canners. This was a decline of 6 per cent in the number of cases packed and 4 per cent in value compared with the previous year. The pack of whole and minced clams amounted to 173,194 standard cases (2,597,910 pounds net weight of clam meats), valued at $2,029,484, while the production of clam chowder, juice, broth, and nectar totaled 1,006,580 standard cases (30,197,400 pounds gross weight), valued at $6,300,155.

Product, State and Number of Plants	Standard cases: Whole and minced		Chowder, Juice, Broth, and Nectar		Total	
	Cases	Value	Cases	Value	Cases	Value
Soft clams						
Maine (12)	107,177	$1,098,863	166,521	$945,204	273,698	$2,044,067
Razor clams:						
Washington (4)	9,393	161,312	—	—	9,393	161,312
Alaska (11)	27,539	494,402	—	—	27,539	494,402
Total razor clams	36,932	655,714	—	—	36,932	655,714
Hard clams: [1]						
Mass. (1), Rhode Is. (1), New York (6)	19,332	164,843	67,072	357,631	86,404	522,474
New Jersey (1), Penn. (1), Maryland (1)	—	—	770,685	4,989,857	770,685	4,989,857
Washington (4)	9,679	108,684	2,100	6,856	11,779	115,540
Alaska (1)	74	1,380	202	607	276	1,987
Total hard clams	29,085	274,907	840,059	5,354,951	869,144	5,629,858
Grand total (43)	173,194	2,029,484	1,006,580	6,300,155	1,179,774	8,329,639

[1] Includes the pack of surf clams in New York.
Note: Standard cases represent the various sized cases converted to the equivalent of 48 No. 1 cans, each can of whole and minced clams containing 5 ounces of meat, drained weight; and each can of chowder, juice, broth, and nectar, 10 ounces, gross content. The production of canned whole clams totaled 61,850 standard cases, valued at $760,126; minced clams, 111,344 standard cases, valued at $1,269,358; clam chowder, 983,584 standard cases, valued at $6,219,480; and canned clam juice, broth, and nectar, 22,996 standard cases, valued at $80,675.
Source: U. S. Fish and Wildlife Service.

TABLE 126. PACK OF CANNED CLAMS AND CLAM PRODUCTS, 1939 TO 1948.

Year	Whole and minced: Soft clams[1] Standard cases	Whole and minced: Hard clams Standard cases	Whole and minced: Razor clams Standard cases	Chowder, Juice Broth and Nectar Standard cases	Total: Standard cases	Total: Value
1939	117,602	42,056	76,315	699,174	935,147	$3,798,319
1940	124,697	38,851	74,565	689,515	927,628	3,778,363
1941	97,460	32,303	40,192	757,388	927,343	3,711,029
1942	72,499	30,515	40,104	639,484	782,602	3,791,058
1943	47,746	28,344	40,340	348,364	464,794	2,802,420
1944	72,434	71,771	40,450	363,041	547,696	3,820,612
1945	64,425	238,475	63,703	533,429	900,032	7,391,098
1946	167,987	108,638	79,394	1,171,770	1,527,789	11,145,047
1947	33,968	24,863	47,407	1,151,424	1,257,662	8,642,235
1948	107,177	29,085	36,932	1,006,580	1,179,774	8,329,639

[1] The production of canned surf clams in Maine has been included with the pack of soft clams.

Source: U. S. Fish and Wildlife Service.

was occasionally eaten by man; during World War I it came into prominence as a source of food and continues to be marketed in considerable quantities. At the same time the ocean quahog (*Arctica islandica*) came into more general commercial use. This clam resembles in size and shape the hard clam or ordinary quahog. It is found in water from 80 to 120 feet deep, buried in the muddy bottom. The outside of the shell is covered with a dark brown or black membrane. It is principally used in minced form for chowder. Very little is known of its life history. There are a few physiological differences between the two hard clams.

On the Pacific Coast a number of species are utilized. Of these the razor clam (*Siliqua patula*) is perhaps the most highly esteemed. It is used both fresh and canned. The Atlantic species (*Mya arenaria*) has become widely established and in some regions forms the basis of a considerable fishery. Other clams of commercial importance are: *Tivela stultorum,* the "Pismo clam"; *Paphia staminea,* known as "littleneck clam" or "rock cockle"; *Schizothaerus nuttalli,* variously known as "Washington clam," "great Washington clam," "great blue clam," and "gaper"; two species of *Saxidomus–Saxidomus nuttalli* and *Saxidomus giganteus,* which also are called "Washington clam" (not because of their distribution) and sometimes "butter clam"; and *Macoma nasuta,* the "bent-nose clam."

Life Histories of Most Important Species of Clams Utilized Commercially

Mya arenaria, commonly called "soft clam," "long clam," "long neck," "squirt clam," "mananose," "sandgaper," and "old maid," is found from South Carolina to the Arctic Ocean. It is the principal species north of New York. About 1870 this clam was introduced into Pacific Coast waters, and it is now widely distributed along the Pacific Coast.

The life history of this clam is very interesting. The male and female cells are

extruded into the water where they unite and form a swimming embryo which rotates spirally. When the little clam has grown to be about 0.003 inch in diameter, an embryonic shell appears. The length of the swimming period varies somewhat with the temperature of the water, being, according to Shellford, from 3 to 6 days in length. Millions of these young swimming clams can be found over the clam flats during the reproductive season, which lasts from the middle of June until September in waters along the Atlantic Coast south of Cape Cod. A muscular foot, a siphon, and gills appear during the later part of the swimming stage. The projecting pad covered with the swimming cilia, called the "velum," gradually disappears, and the small clam soon settles to the bottom. When it reaches the bottom, a glandular fluid is secreted, which, on being ejected into the water, hardens into a minute thread, called the "byssus"; the tiny clam attaches itself to shells, seaweeds, or pebbles by means of this thread. It does not remain stationary at this stage, but often detaches the byssus and creeps about by means of its foot. When the shell has become about 0.01 inch in length, the young clam begins burrowing into the bottom. When completely buried it spins another byssus and again attaches itself. Occasionally, newly buried clams discard the thread, come to the surface, creep a short distance, and then burrow into the bottom again. When the young clams become about half an inch long, they burrow deeper into the bottom and are believed to remain buried through the rest of their lives. Clams grow from a length of 1 inch to about 3 inches in a single year.

Venus mercenaria is commonly called "quahog" or "quahaug," "hard clam," "round clam," and in the smaller sizes "cherry stone" and "littleneck"; this clam is common from Cape Cod to Texas. South of New York the quahog is much more abundant than the soft clam and, therefore, is simply called "the clam." Its life history has been studied by Belding (1912) and has been found to be strikingly similar in the early stages to that of *Mya arenaria,* which has been described above; however, the growth of *Venus mercenaria* to commercial sizes is decidedly slower.

The geoduck *Panope generosa,* found only on the Pacific Coast, is of no commercial importance, but is mentioned here because it is the largest of all the clams. Single clams of this species are often more than 8 inches in length and weigh more than 10 pounds. This clam burrows in the mud and sand as deep as 3 to 4 feet and sends its siphon to the surface. In most areas it is protected by the prohibition of commercial exploitation and the setting of a low-bag limit for home use.

Siliqua patula is the most important native Pacific Coast clam and is found on nearly all the sandy beaches from Oregon to Alaska. They obtain their name "razor" from their shape, being rather long and narrow. When disturbed they burrow rapidly into the sand to a depth of 2 or 3 feet, forming large elliptical holes.

Chemical Composition

Numerous proximate analyses of clams have been published, but to the authors' knowledge no comprehensive researches on the composition of clams have been carried out. The data (Table 127) concerning the composition of soft and hard clams were taken from Atwater's analyses, as presented by Langworthy.

TABLE 127. APPROXIMATE COMPOSITION OF CLAMS.

	Refuse Shell, etc.	Moisture	Protein (N × 6.25)	Fat	Carbo-hydrates	Mineral Matter	Total Nutrients
	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Soft clams in shell	41.9	49.9	5.0	0.6	1.1	1.5	8.2
Soft clams canned	—	84.5	9.0	1.3	2.9	2.3	15.5
Quahogs, removed from shell	—	80.8	10.6	1.1	5.2	2.3	19.2
Quahogs in shell	67.5	28.0	2.1	0.1	1.4	0.9	4.5
Quahogs canned	—	82.9	10.5	0.8	3.0	2.8	17.1

Source: Langworthy, C. F., "Fish as Food," U. S. Dept. Agr., *Farmers' Bull.*, **85**, *Revised* (1907).

Contamination by Pathogenic Organisms

Clams are liable to bacterial contamination by the same organisms found in oysters growing in polluted saline waters. Oystermen are able to establish their beds far from shore where there is danger of contamination by sewage from nearby cities and towns. Since the soft clam (*Mya arenaria*) and the razor clam (*Siliqua patula*) are found chiefly on the shore between tide lines, there is much more danger of contamination by polluted waters. Clams dug in the vicinity of large cities should always be cooked before being eaten. Steaming, baking, and frying quickly kill pathogenic organisms, such as *Bacillus typhosus* which may be present.

During certain seasons of the year clams taken from areas where they have been feeding on a reddish or pinkish colored organism may cause sickness. This organism is particularly prevalent on the Pacific Coast and the resulting sickness is commonly known as "mussel poisoning." State Health and Fisheries authorities usually post notices in the affected areas and prohibit the digging of clams for either commercial or individual use until the area is clear.

Clam Culture in New England

Because of the great decline of the New England clam fisheries much has been done to encourage clam farming. Numerous detailed reports concerning its feasibility have been published by the Fish and Game Commission of Massachusetts. The culture of both the hard and the soft clam is carried out in a limited way in New England. Small areas are found in nearly every harbor where small soft clams (seed clams) are found in enormous numbers at certain seasons of the year. These heavy sets run as thick as 2,000 per square foot of surface. The seed clams are usually obtained from the areas of heavy set by washing the small clams out of the sand or mud by means of a cradle-shaped sieve. The small clams are "planted" on suitable tidal flats and grow to marketable size within a year or two.

In many areas where the water is polluted with both sewage and industrial wastes the clams are removed to water which is free from contamination. Clams so handled soon become clean and suitable for marketing. One plant in operation

handles clams from contaminated areas by washing them with chlorinated sea water. This is quite an expensive method, and it is doubtful that it could be universally adopted.

The collection of seed clams or spat is much more difficult in the case of the quahog clam inasmuch as the small hard clams are never found in vast quantities. Although as many as 75 young quahogs per square foot may sometimes be caught in box spat collectors, this method has not proved profitable. Since the young quahogs (littlenecks) bring high prices, methods of quahog farming for the production of littleneck clams have been suggested. By this system the larger older quahogs are kept as seeders, the littlenecks alone being marketed.

Clam Cultivation in Japan

Glud (1947) has described the cultivation of several species of clams in Japan. In certain areas of the coast practically all of the clams used result from cultivation. Tiny clams, from ⅜ to ⅝ inch in diameter, are dredged with a basket-type apparatus, equipped with a screen for separating the small clams from the sand. They are usually taken at the mouths of rivers because the low salinity of the water and food supply produce better sets. The clams are taken to the new area and spread over the mud where they are left to burrow for a year or two. In this length of time the *Paphia phillipenarum* will grow to 1 inch in diameter, which is the usual market size, and the *Meretrix meretrix* will increase in size from 2 to 2½ inches and be ready for the market.

Atlantic Coast Industry

Soft Clam. The early New England settlers soon learned of the valuable beds of soft-shell clams that existed on many of the tidal flats along the Atlantic Coast. In times of want the early colonists depended upon this natural food supply which was so readily obtainable. There was some local trade in clams; but as there were no inland markets, the demand was limited. Early in the nineteenth century the fishermen began to use large quantities of clams as bait. About 1875 the value of the clam as food began to be recognized more generally throughout the eastern states. A period of overfishing followed which depleted many of the most valuable clam flats. Now, much attention is being given to the restocking of the exhausted beds.

Two methods of digging soft clams are commonly employed; one of these, called "wet" digging, is carried on when water is over the clam flats, whereas "dry" digging takes place when the beds are left exposed by the tide. Dry digging is by far the more common practice. Submerged clams are dug with an enlarged clam hoe, known locally as a "sea horse," which has prongs 12 to 14 inches long and a strong wooden handle about 4 feet long. This handle has a belt attachment which is buckled around the clammer. The sea horse is worked deep into the loose sand and dragged by one man, who wades in the shallow water over the submerged flats while his partner follows gathering the clams upturned by the sea horse. Forks or hoes are occasionally used for this wet digging.

The rake or digger used in dry digging much resembles a potato digger, but varies with the soil of the clam flat. If the soil is loose and sandy or gravelly, diggers with broad prongs are used; but for hard mud flats, they should have thin, sharp prongs. The angle which the handle makes with the prongs of the hoe is

a matter of choice among individual clam diggers, and should vary from a right angle to an angle of 60 degrees. In a few districts spading forks are used by the clammers. The baskets used for holding the clams gathered by the diggers are usually made of uniformly spaced lath so as to permit draining and easy washing. Inasmuch as the dry digging of clams is possible only between tides, the work lasts only a few hours at a time. Usually from 1 to 4 bushels of clams are gathered, but this amount varies widely with different individuals and with the abundance of the clams.

Clams are either marketed in the shell or "shucked out." In either case they must be carefully washed. Small clams suitable for steaming are ordinarily shipped to market in the shell, as are also the fine-appearing sand clams. The unprepossessing mud clams and the very large clams are usually shucked by removing the shell and the external covering of the siphon or neck. A bushel of clams produces about 7 quarts of shucked clams. Shucked clams readily absorb a considerable quantity of fresh water; after soaking for about 6 hours they increase in volume about a third. Consequently, the shucked clams are soaked before being marketed. In addition to increasing their bulk the soaking process plumps the clam meats.

The clams shipped in the shell are usually packed in second-hand flour and sugar barrels, while shucked clams are usually shipped in kegs or butter tubs. The chief markets for soft clams are Boston, New York, Baltimore, and Philadelphia.

Hard Clam. Inasmuch as the quahog clam was considered inferior in quality to the soft clam, little attention was given to it commercially until about the beginning of the nineteenth century. But the hard-clam fishery did not become of great importance until the beginning of the twentieth century when the popular demand for "littlenecks" or the small quahog clams spurred production to the limit of the natural clam resources.

There are two types of quahog fisheries on the Atlantic Coast—the deep sea and the shallow water; the former is by far the most productive.

The quahog fishery of the Atlantic Coast is located chiefly in Massachusetts, Rhode Island, New York, North Carolina, and Florida. Quahogs occur, however, all along the Atlantic Coast, from Massachusetts to Florida, and along the coast of the Gulf of Mexico. The chief centers of the industry in Massachusetts are Chatham, Eastham, Edgartown, Fairhaven, Orleans, Wareham, and Wellfleet. The culture of quahogs is carried on chiefly in Orleans, Eastham, and Wellfleet. The quahog fishery is an important industry in Long Island Sound and in the various Long Island bays, notably Great South Bay. The North Carolina clam industry is centered in Brunswick, Carteret, New Hanover, and Pender counties. There are still great beds of these clams in the south that have never been disturbed. Many beds are found along the shores in the Gulf States, but they are dug commercially only on the west coast of Florida.

The Indians obtained their hard clams by the primitive method of "treading"; the "treader" finds the clams by wading about barefoot in the shallow water, feeling with his toes in the soft mud for the quahogs, and then picking them up by hand. The early settlers soon learned more rapid ways of gathering shellfish. Some quahogs are obtained by raking them out of the mud on the exposed tidal flats by means of short rakes or hoes. Because of the scarcity of hard clams between the tide lines this method is now chiefly employed by fishermen seeking

clams for their own use. Some clams are also gathered by means of oyster tongs or clam tongs of similar design. This method is applicable only in shallow water as the tongs are seldom longer than 16 feet. Tonging is carried on in small coves and inlets where the water is usually very quiet. By far the most important way of taking quahogs is by means of rakes. Belding (1909) has described the various types of rakes used in the quahog fishery of Massachusetts.

In some localities a rake resembling a potato digger, with 4 or 5 slender prongs, is used. It is usually equipped at the back with wire netting to help in holding the clams when they are dug. A handle about 5 feet long makes it possible to use this digger in shallow water or on the flats when the tide is out. This method is used more often in digging for home consumption than for the market. In some areas an ordinary garden rake with a wire netting basket is used in shallow water. This equipment can be used from either a wading or boating position. Since the rake is wider, digging is more rapid.

A regular clam rake may vary in width and length of handle. The width of the rake probably averages about 10 inches and has a handle about 6 feet long. The teeth or prongs are set about an inch apart, and are bent in the shape of a semicircle so that the clams are retained more easily. This type rake is particularly adapted for shallow-water digging.

A basket rake is one that is particularly adapted to use in deep water. The handle may vary between 25 and 65 feet in length and is about 1½ inches in diameter. Wood is preferred for the handle because of its light weight. The end of the handle is fitted with a cross piece to aid in dragging the rake across the clam bed. A basket of wire or netting is attached to the back of the rake to retain the clams.

The basket rake is ordinarily handled from a small boat. When the fishing ground is reached, an anchor attached to a long rope is dropped overboard; then the boat is moved a distance of 5 or 6 hundred feet and another anchor attached to the same rope is dropped overboard. The long rope is attached to the bow of

(*Courtesy Providence Journal-Bulletin*)

FIG. 27–1. Digging quahog clams with long handle bull rake.

the boat in such a way as to permit the boat to swing freely along its length. The rake is lowered from the bow of the boat and the teeth are worked into the sand or mud of the bottom. The rake is then pulled toward the stern of the boat and lifted out of the water. The contents are dumped onto the culling board, or

(*Courtesy Providence Journal-Bulletin*)

Fig. 27–2. Dredge boat digging clams with the chain link dredge.

the clams are picked out of the basket and the debris is thrown overboard. As one spot becomes exhausted of clams, the boat is moved along its anchorage and a new spot is dragged. This method of clam fishing is usually carried out between ebb and flow tides to avoid the excessively deep water at high tide.

Where clams are plentiful on private oyster grounds, the ordinary oyster dredge may be used. For deep-water beds, such as occur near Nantucket, a special narrow, long-toothed, "deep-water clam dredge" has been developed.

The hard-clam fishery is essentially a summer fishery; the season in Massachusetts lasts for 7 months, usually starting the last of March and ending about the first of November.

The clams are washed soon after they are brought ashore and graded into various sizes; the most generally recognized grades (in Massachusetts) are "littlenecks," "sharps," and "blunts." The "blunts" and "sharps" are the larger grades and are alike in every particular except the thickness of the edge of the shell. The "blunts" are thick-lipped and have a somewhat heavier shell than the "sharps," which are usually lighter in color and have sharp edges. The following dimensions are illustrative of the size of the grades: "Littlenecks," small, 1.5 to 2.25 inches; large "littlenecks," 2.25 to 3 inches; medium "sharps," 3 to 3.75 inches; and large "sharps," 3.75 inches up. Large "littlenecks" correspond approximately with the size known on Long Island and in the New York market as "cherry stones."

(Courtesy Providence Journal-Bulletin)

FIG. 27–3. The dredge is dumped by means of an opening at one end. The clams are then culled while the dredge is being towed by the boat.

The quahogs are shipped either in barrels or bags. Holes are cut in the bottom and sides of the barrels to allow circulation of air and to permit drainage of water; burlap is used instead of wooden heads.

If the market for the hard clams is slow at the time of catching, the clams are often bedded in sand on the tidal flats until the market improves. The fisherman

has only to spread his catch on the surface and the quahogs will burrow into the sand and continue their growth. Some fishermen spread their catch on floats which they lower into the water so as to keep the clams alive until needed. The advantage of the use of floats is that the clams need not be dug a second time and may be easily and quickly obtained for market when desired.

The chief markets for New England quahogs are Boston and New York. Quahogs will live out of water very much longer than the soft clam. It may be safely shipped far inland even in summer. It is therefore better known in the markets of the Mississippi Valley than the soft clam.

Frozen Clams

At the end of December, 1949 there were 189,970 pounds of clams in cold storage; this is about the monthly average for this sea food. The greater portion of these were being held for future use in canned products such as chowder. They are packed in telescope-top tin cans or in waxed cartons, with a capacity of 5 pounds each. There are very few frozen clams packed in small 1-pound family-size containers. All those frozen are cleaned ready for use as soon as they are defrosted.

Pacific Coast Industry

The chief commercial clam of the Pacific Coast is the so-called razor clam (*Siliqua patula*). The most important clam fisheries of the Pacific Coast are located in Clatsop County, Oregon; Grays Harbor and Pacific counties, Washington; and near Cordova, Alaska. This clam is usually found in the sand between the tide lines. The clammers mostly use short-handled spades for digging. The clams are most numerous near the low-water mark; because of this the best digging is during the spring tides when the greatest run-out occurs at low tide. Because of the danger of overfishing a closed season has been inaugurated in Washington from June 1 to September 1.

Preservation

Canning. The only important means of preserving clams is by canning. Small quantities of clams are preserved by other methods, including pickling, salting, drying, and smoking; but the amount of clams preserved in the United States by these methods is insignificant. However, the Japanese dry considerable quantities of clams.

The quantity and value of clams and clam products canned by states in 1948 are given in Table 125 (p. 577).

Several species of clams are canned both whole and minced. The general procedure, excepting the removal of the siphon, is similar for all species. In some canneries this is included with the whole meat as it increases the yield to a considerable extent. This is usually the practice when the clams are minced for canning.

Much labor-saving machinery is employed in the more modern clam-canning factories. Several of the up-to-date plants employ automatic shucking machinery. The automatic shucker consists of a long rectangular box containing a rack which is operated as a rocker. The motion of the rocker carries the clams toward the

opposite end of the trough and through hot water which causes the clams to gape. The motion of the rack shakes the meats out. When the meats and shells reach the opposite end, jets of cold water are played upon the meats to cool them rapidly in order to prevent them from becoming tough. The meats are then picked off the frame and placed in large pans while the shells pass on and are dumped outdoors.

The meats are then dressed and cleaned. This is accomplished by splitting them on one side with scissors so that they are opened wide. The dark mass near the end of the siphon which contains much sand and dirt is clipped off. The cut meats are washed in a special washing machine, consisting usually of a cylindrical perforated drum which revolves half a turn in one direction and then half a turn in the opposite direction. The siphon and side walls are cut away from the washed meats and discarded, and the stomach is slit open and cleaned out. The cleaned, dressed meats are minced in a meat grinder. The ground meats are placed in the hopper of an automatic filling machine which feeds the desired quantity of clam meat into the cans which pass under it on an endless belt. Some of the juice of the clams which runs out during the dressing process is added to the filled cans. The tops of the cans are put in place and the cans are exhausted at about 210° F (99° C) for about 8 minutes. The tops are then sealed and the cans are processed at about 220° F (104° C). One-pound cans are processed for 90 minutes, and half-pound cans are heated for 70 minutes. After processing, the cans are quickly cooled with streams of cold water to prevent the clam meat from becoming tough.

Clam Nectar. During the grinding of the meats of clams a considerable quantity of liquid is expressed. Although some liquor is added to each can, a considerable surplus remains. This is canned separately and sold as clam nectar. The hot liquor is placed in 1-pound cans which are then sealed and sterilized. If the liquor is cold when canned, the cans are exhausted before sealing in the same manner as in the canning of razor clams. The 1-pound cans of nectar are cooked in an autoclave for an hour at 240° F (116° C).

Clam liquor is also obtained from clams of the genus *Donax,* too small for utilization in any other way.

Clam Chowder. Clam chowder for canning is usually prepared from the hard or quahog clam inasmuch as this clam possesses a pronounced clam flavor. If milk is used as an ingredient in the preparation of chowder, it is necessary to add small quantities of a citrate or phosphate to prevent separation.

The preparation of clam chowder has been described by Cobb (1919). The formula includes the following proportions: 2500 quahog clams, 25 pounds of bacon, 25 pounds of white potatoes, 7 pounds of onions, 25 pounds of tomatoes, ¼ pound of chopped parsley, ⅛ pound of thyme, 1 ounce of sweet marjoram, 1 pound of salt, ½ pound of ground white pepper, and 15 gallons of water. The clams are thoroughly washed, drained, and chopped; potatoes and bacon are diced; then all ingredients are boiled for 10 minutes, after which the whole is placed in cans and sealed. When filling the cans it is necessary to stir constantly. The No. 3 cans are processed for 80 minutes at 250° F (121° C); quart cans are processed for 50 minutes at the same temperature.

Condensed clam chowder is prepared by the same formula, except only half the above quantity of water is used. The cans are filled with the solids, and the

liquid is added to cover the contents. The processing time at the above temperature is 40 minutes for No. 1 cans.

Jarvis (1943) gives the following recipe for Manhattan-style clam chowder:

65 pounds cracker crumbs	24 No. 10 cans of tomatoes
18 " ground salt pork	16 pounds salt
18 " ground onions	5 ounces white pepper
55 gallons water	

When this chowder has been cooked and is ready to be canned, 2 ounces of clams are put into each No. 1 can and sufficient liquid is added to fill the can.

In New England clam chowder from ¼ to ½ of the water is replaced by clam juice. The clams are added either whole or coarsely minced rather than ground. Diced blanched potatoes are substituted for tomatoes. The clams and potatoes are placed in the can and the liquid ingredients are then added to fill the can.

The Federal Food and Drug Administration has set forth regulations as to sanitation in the cannery, the required fill of the can, both solids and liquids, and labeling. It is required that the drained weight shall equal 3½ ounces for ½-pound flat cans, 5 ounces for a No. 1 picnic size, and 8 ounces for a No. 1 tall can.

Clam Extract. Clam extract finds extensive use as a food for convalescents and invalids. It is usually prepared by placing fresh clams in the shell on racks or gratings in an autoclave. The clams are steamed for about 20 minutes; the heat cooks the clams and causes much of the juice to run out. The liquor is collected in pans under the racks. This liquor is filtered and concentrated by boiling. The concentrated extract is put into cans which are topped, sealed, and sterilized by processing in an autoclave at 240° F (116° C). One-pound cans are heated for an hour, whereas half-pound cans are usually heated for 50 minutes at this temperature. Various other methods of preparing clam extract are occasionally used.

Smoking, Salting, and Drying. Large quantities of clams used for fish bait by New England fishermen were formerly shucked, that is removed from the shell, and salted in barrels. The gradual decline of the hand-line fishery effected a similar decline in the clam-bait industry; at present only a few barrels of salted clams are prepared annually for use as bait.

Smoking and drying were the earliest means of preserving clams. The North American Indians strung clams on sticks or cords and dried and smoked them over camp fires. Even today, the Japanese and Chinese dry large quantities of clams and other shellfish. The Japanese dry a clam (*Solecurtus constrictus*) resembling the razor clam.

By-products

Shells are the only by-products of the clam industry. Inasmuch as the clam shell possesses little value, its use is limited to oyster cultch, material for the construction of roads, and poultry grit.

REFERENCES

Ackerman, E. A., "New England's Fishing Industry," Chicago, Univ. of Chicago Press, 1941.

Anon., "The Ocean Quahog Fishery of Rhode Island," a survey conducted by the U. S. Department of the Interior, Fish and Wildlife Service, in cooperation with the Divi-

sion of Fish and Game of the Department of Agriculture and Conservation of the State of Rhode Island (1945).

Arcisz, W., and Sandholzer, L. A., "A Technological Study of the Ocean Quahog Fishery," U. S. Fish and Wildlife Service, *Commercial Fisheries Review*, **9**, No. 6, 1–21 (1947).

Belding, D. R., "The Mollusk Fisheries of Massachusetts," Boston, Mass. Fish and Game Commission, 1909.

Belding, D. R., "Quahog and Oyster Fisheries of Massachusetts," Mass. State Biologists Rept. (1912).

Belding, D. R., "The Soft-Shelled Clam Fishery of Massachusetts," Mass. Dept. of Conservation, *Marine Fisheries Ser.*, **1** (1931).

Bonnot, P., "The Edible Bi-valves of California," Calif. Fish and Game, **26**, No. 3, 212–239 (1940).

Cobb, J. N., "Canning of Fishery Products," Seattle, Miller Freeman, 1919.

Coe, W. R., and Turner, H. J., "Development of the Gonads and Gametes in the Soft-Shell Clam (*Mya arenaria*)," *J. Nutr.*, **15**, 1 (1938).

Frazier, C., "The Spawning and Free Swimming Periods of *Saxidomus* and *Paphia*," *Trans. Royal Soc. Can.*, Sec. 4, **23**, 195–198 (1929).

Frazier, C., "Notes on the Ecology of the Cockle," *Trans. Royal Soc. Can.*, Sec. 5, **25**, 59–72 (1931).

Frazier, C., and Smith, P., "Notes on the Ecology of the Butter Clam," *Trans. Royal Soc. Can.*, **22**, 271–286 (1928).

Glud, J. B., "Observations on the Japanese Clam Fisheries," Washington State Dept. of Fisheries, *Bull.*, **47**, 34–41 (1947).

Hertzler, R., "Personality Clam," *Nature Magazine*, **43**, No. 9, 76–79 (1950).

Johnson, M. E., and Snook, H. J., "Seashore Animals of the Pacific Coast," New York, Macmillan Co., 1927.

Langworthy, C. F., "Fish as Food," U. S. Dept. Agr., *Farmers Bull.* **85**, *Revised* (1907).

Loosanoff, V. L., "Effect of Temperature upon Shell Movements of Clams, *Venus mercenaria* (L.)," *Biol. Bull.*, **76**, 171–182 (1939).

Newcombe, C. L., and Kessler, H., "Variations in Growth Indices of *Mya arenaria* L. on the Atlantic Coast of North America," *Ecology*, **17**, 3 (1936).

Quale, D. B., "The Edible Mollusks of British Columbia," *British Columbia Fish Dept. Rept.*, **1940**, J75–J87 (1941).

Ricketts, E. F., and Calvin, J., "Between Pacific Tides," Stanford Univ. Press, 1939.

Schroeder, W. C., "Clam Resources of the Ten Thousand Islands, Fla.," U. S. Bureau of Fisheries *Economic Circular*, **46** (1920).

Schroeder, W. C., "Fisheries of Key West and the Clam Industry of Southern Florida," U. S. Bureau of Fisheries *Doc.*, **962** (1923).

Westman, J. R., "Surf Clam Industry Has Rapid Growth," *Atlantic Fisherman*, **27**, No. 7, 21, 30 (1946).

Weymouth, F. W., McMillin, H. C., and Holmes, H. B., "Growth and Age at Maturity of the Pacific Razor Clam, *Siliqua patula* (Dixon)," U. S. Bureau of Fisheries *Doc.*, **984** (1925).

CHAPTER 28

The American Shrimp Industry

Introduction

The total production of shrimp in the United States and Alaska in 1945, the last year for which complete statistics are available, was 191,345,000 pounds, valued at $21,369,000. Approximately 98 per cent of this total (189,023,700 pounds, valued at $21,288,837) was produced in the South Atlantic and Gulf States. Louisiana was the largest producer, with a total of 116,904,200, valued at $13,894,223. Table 128 contains a breakdown of the production of shrimp by states for the 1948–1949 season.

TABLE 128. SHRIMP PRODUCTION, 1948–1949 SEASON.

The following table shows the production of shrimp in the South Atlantic and Gulf States, as reported by the various state conservation agencies concerned. All statistics are in pounds, heads on. Conversions have been made on a basis of 210 pounds heads on, per barrel and the equivalent of 125 pounds heads off, per barrel. Data are preliminary and subject to revision.

Shrimp Production, South Atlantic and Gulf States
January–June, 1949 [1]

State	January	February	March	April	May	June	Seasonal total July 1, 1949–June 30, 1949
	Lbs.[2]	Lbs.[2]	Lbs.[2]	Lbs.[2]	Lbs.[2]	Lbs.[2]	Lbs.[2]
North Carolina	110,880					605,472	7,058,488
South Carolina						1,061,926	8,295,022
Georgia [3]	585,168	100	378,352	379,584	1,652,116	1,445,184	11,215,877
Florida	[4]	[4]	[4]	[4]	[4]	[4]	[4]
Alabama	57,750	54,600	17,220	19,110	18,900	62,790	1,859,400
Louisiana and Mississippi	4,592,280	2,285,010	2,008,860	4,085,340	7,103,250	5,302,500	77,681,910
Texas	445,666	[4]	[4]	[4]	[4]	[4]	[4]

[1] As reported to the following state agencies: North Carolina Department of Conservation and Development, South Carolina Board of Fisheries, Georgia State Game and Fish Commission, Alabama Conservation Department, Mississippi Seafood Commission, and Louisiana Department of Wildlife and Fisheries.

[2] To convert heads on to headless, multiply by .595.

[3] Data for Georgia represent the sale of prepaid tax stamps, instead of actual landings.

[4] Not available.

Source: U. S. Fish and Wildlife Service.

Species of Shrimp Making Up the Catch

Out of a number of species of shrimp in the South Atlantic and Gulf States only five are of commercial importance. According to Anderson, Lindner, and King (1949) these are: the common shrimp (*Penaeus setiberus*); the 3-grooved

shrimp (*P. aztecus*), (*P. duoarum*), and (*P. brasiliensis*); and the "sea-bob" or "seven beards" (*Xiphopenaeus*). The three species of *brasiliensis* were formerly included in one species of grooved shrimp. However, it was proven by Burkenroad (1939) that these constituted three distinct species.

According to the estimates of the above investigators the common shrimp (*P. setiferus*) is by far the most numerous of these five species. Although the percentage composition of the catch varies to some extent from year to year, this species composes approximately 95 per cent. The fishermen do not ordinarily distinguish between the various species. Occasionally when the catch contains a larger proportion of the *brasiliensis* group, sales resistance is encountered because of the slight difference in color. This group is commonly called "brasilian" shrimp or "brownies."

The most abundant of the grooved shrimp is *P. aztecus*, with *P. duoarum* second and *P. brasiliensis* last. The largest production of this group of shrimp is during the late spring and early summer. Several other species are taken by the trawlers, but the quantity is quite small and in some cases the identity is not entirely clear.

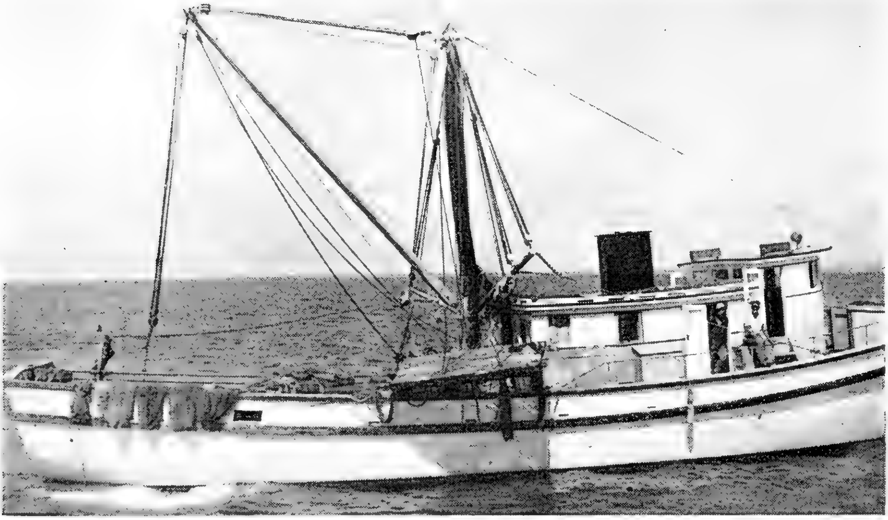
Handling Shrimp on the Vessels

Shrimp are one of the most popular of all sea food products available to the consuming public; consequently, there is an almost universal demand for it throughout the year. The requirements for supplying the market are satisfied by the wide distribution of the fishing grounds and the success with which a good quality product can be preserved by freezing and canning. Some states have closed seasons on shrimp fishing. They do not run concurrently, however, so shrimp are caught somewhere in the area throughout the year.

Practically all shrimp are captured by means of a trawl which is towed slowly along the ocean floor. This trawl is a large funnel-shaped bag flattened at the top; otter boards on the right and left sides hold it open so that the shrimp can be entrapped. At intervals, depending upon the volume of shrimp in the bag, it is hoisted aboard the vessel and emptied on the deck. The net is again thrown overboard for another drag while the crew of the vessel separate the shrimp from the various other species which may also have been caught in the trawl. As the shrimp are sorted, they are stored with alternating layers of ice in bins in the hold of the vessel until the bins are full. Some crews, while at sea, remove the heads. This saves considerable space in the storage bins since the tails of the shrimp are the only edible portion and, therefore, are the most valuable. When the shrimp are landed whole, the head portion is sent to a meal plant and manufactured into shrimp meal, which is valuable as a poultry feed.

This first handling operation aboard the vessel has a particular bearing on the market value of the shrimp. If permitted to lie on the deck of the vessel in the hot sun for several hours shrimp deteriorate rapidly, and, as a result, the quality is reduced. No matter whether the shrimp are to be sold fresh, cooked, canned, or frozen, they must be packed in adequate ice at the earliest possible time. Care should be exercised in handling to be sure that the shrimp are not injured since a bruise causes more rapid deterioration by reason of enzymatic and bacterial action.

The vessels journey for 10 to 50 miles to obtain their catch. They fish in waters



(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 28–1. The southern shrimp otter trawler with gear ready to set.

(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 28–2. Shrimp trawling off the central Louisiana coast. The men are straightening the trawl board. The culled fish are in the left foreground.

ranging from 18 to 50 feet in depth, and remain at sea from 10 to 15 days, depending upon their success in obtaining a pay load.

It has been established that as much as 10 per cent of the catch is often lost because it is bruised and improperly iced while being headed and stored in the hold of the vessel. When shrimp are plentiful and the crew are busy taking care of the catch as it is hauled aboard, it is not possible to find time to remove the heads before packing the shrimp in ice. This results in a much more rapid spoilage since bacteria and enzymes from the viscera infect the remainder of the shrimp and cause rapid softening. Another type of spoilage occurs when the shrimp are held in ice over a prolonged period, and results in a distinct stale shrimp odor. At the same time a black discoloration often develops on the flesh directly under the shell. In extreme cases this black discoloration causes a similar discoloration in the water from the melting ice flowing over the shrimp, and is known as "black drip." If the shrimp are left uniced on deck for a prolonged period, they develop a red discoloration under the shell, and are known as "red shrimp." These are recognized as unmarketable by all shrimp fishermen.

Method of Capture

Prior to 1912–15 most shrimp were taken in haul seines. About this time, at the Beaufort, N. C. biological station, the small otter trawl came into use for gathering specimens for study. The otter trawl was so successful in taking shrimp that the industry began to adopt this method in preference to the haul seine. The first commercial operation to make use of the otter trawl was located at Fernandina, Fla. Seines were so rapidly replaced by the trawl that in the early 1930's only a few remained in operation; at present none is in use.

The introduction of the trawl is of considerable economic importance in the development of this fishery. The haul seine could be used only in relatively shallow water and required a large crew of men, while the otter trawl is handled by a small crew and can be used in deep water. The catch is considerably greater with a trawl since its use made possible the opening of new fishing grounds. In the deep water of the Gulf the schools of shrimp are located by means of a small "try net," which is similar in construction to the large trawl. This saves time and effort as the large trawl is not put overboard unless there are good indications that a quantity of shrimp is in the area.

Power boats of various sizes are employed in the otter-trawl fishery, but as a rule the crew consists of 2 men. Many small boats, however, with crews of 1 man each, successfully engage in this fishery, while a few of the larger boats carry 3 men.

As the vessel leaves port for the fishing grounds, the net is arranged on deck at the stern, the mouth of the bag being placed on deck first and the tail end on top. The otter boards are placed on either side of the deck, bridles up, and the towlines are coiled in the hold. When drags with the try net indicate sufficient quantities of shrimp are present, the engine is slowed down so that the boat does not travel more than from 2 to 4 miles per hour. The tail end of the net is first thrown overboard and the remainder of the trawl quickly follows, the boards being the last to go. The amount of towline let out in hauling the trawl varies, being usually about 3 times the depth of the water. The lines are attached to cleats on either side of the vessel, the point of attachment varying in the different boats.

However, best results seem to be obtained by attaching the lines as nearly amidships as possible as it facilitates the steering of the vessel during the trawling process.

After the net has been trawled for about 30 minutes, the engine is stopped and the net hauled in. Two men stand on the stern and pull on the towlines until the otter boards are hauled aboard and the slack of the net hauled in. The tail end of the bag containing the catch is then worked around to the side of the boat and hauled aboard.

Composition

The edible portion of fresh shrimp compares favorably in protein content with fresh fish. However, it has a very low percentage of fat and consequently a low fuel value per pound. Recently various observers have found that many shrimp have a rather high fat-soluble vitamin content; this is of importance in considering their food value. The proximate composition of cooked, canned, and dried shrimp is given in Table 129. The mineral content of shrimp is shown in Table 130.

TABLE 129. ANALYSIS AND FOOD VALUES OF SHRIMP.
(Calculated on the fresh basis)

Constituents	Shrimp (edible portion)			
	Cooked	Canned (dry packed)	Canned (wet packed)	Dry
	%	%	%	%
Protein	27.6	25.5	20.0	71.4
Fat	1.0	0.8	0.5	5.0
Water	64.5	67.7	75.7	12.5
Salt	4.8	2.9	1.9	6.8
Comparative fuel value per pound (calories)	559	505	395	1,540

TABLE 130. INORGANIC CONTENT OF THE EDIBLE PORTION OF SHRIMP.

Mineral	Raw %	Boiled %
Dry matter	20.0	28.7
Calcium	0.0542	0.0614
Magnesium	0.0421	0.0509
Phosphorus	0.2285	0.2432
Iron	0.002188	0.003973
Copper	0.000331	0.000302
Iodine	0.000023	0.000021

Note: Four units to right of decimal point equals parts per million or mg per kg.
Source: Nilson, W. H., and Coulson, E. J., "The Mineral Content of Edible Portions of Some American Fishery Products," U. S. Bureau of Fisheries, *Investigational Rept.*, 41 (1939).

Fresh raw shrimp, analyzed by Coulson (1935), contain the following per cents: moisture, 79.0; protein (N $\times$ 6.25), 17.1; and fat (ether extract), 1.2. Chapman (1926) indicated that shrimp contain 24 parts per million of arsenic; however, Coulson, Remington, and Lynch (1935) report that it is organically combined

in a form that makes it unavailable for absorption during metabolism. Pottinger and Baldwin (1939) report the following per cents of essential amino acids in shrimp meat: Arginine, 7.50; Histidine, 1.61; Lysine, 7.35; Tryptophane, 0.96; and Cystine, 1.25.

Marketing

Iced Shrimp. The bulk of shrimp caught on the Atlantic Coast, particularly in Florida and Georgia, is shipped fresh, principally to northern markets. As a rule the heads are removed. When the shrimp are ready for shipment, they are packed in ice in barrels. Certain markets, however, such as Charleston, South Carolina, and Havana, Cuba, demand the whole shrimp. Since the heads constitute from 40 to 45 per cent of the weight of the whole shrimp, heading prior to shipment is an economical procedure.

Shrimp intended for shipping fresh must be handled with extreme care from the time they are removed from the fishermen's nets until they are placed aboard the train. Shrimp are usually iced as soon as they are put on board the vessel. They should be headed and the bodies thoroughly washed and promptly refrigerated after being landed at the pier. This prevents the accumulation of slime and liquids from the stomach, which is in the head portion.

Alternate layers of ice and chilled shrimp are placed in a barrel provided with drainage holes. A large cake of ice or "header" is placed on top of the barrel. Another method is to place a long narrow cake of ice on end in the barrel and pack the shrimp around the cake. The header cake is placed on top, and the barrel and its contents are covered with burlap.

Cooked Shrimp. Limited quantities of shrimp are cooked in brine previous to shipment. In cooking, the whole or headless shrimp are placed in wire baskets and dipped into boiling 15 per cent brine for 15 to 20 minutes. The cooked shrimp are cooled in a chill room to 35° F (1.7° C) or less, and then shipped in a sealed package, usually a 1-gallon telescope-top tin can, surrounded by ice. Occasionally, live steam is used for cooking shrimp. The shrimp are sprinkled evenly with salt and allowed to stand for a short time. They are then placed in a steamtight box and steamed for half an hour. This process obviates the necessity for making and handling brines, requires less salt, prevents soaking out of flavors, and results in less loss in weight. Sometimes a light brine, which is supposed to act as a preservative, is added to the cooked shrimp when they are packed in tight cans. The brines used contain about 8 per cent salt. Heavier solutions tend to make the shrimp leathery and oversalty; weaker ones produce softness and flabbiness in the stock and have no appreciable preservative effect.

Steamed shrimp, after being cooled, are packed in 1- to 5-gallon shipping tins that are lined with paper and provided with watertight covers which are fastened tightly to the can. The sealed cans are then packed in burlap-covered barrels with drainage holes at the bottom. Such packages are re-iced when necessary by the express company and will remain in good condition even in warm weather.

Canning

If canning is not undertaken at the time shrimp are landed at the cannery dock, they are packed in chopped ice and held until enough shrimp are on hand to justify packing operations. The shrimp go from the fishing vessel, or from the

cold room, directly to the picking tables, where the meat is separated from the heads and shells by women, girls, and boys, who are compensated according to the weight of shrimp headed.

According to the 1945 statistics of production there were 41 shrimp-canning plants, 19 of which were located in Louisiana. The total pack of canned shrimp was 153,551 standard cases, made up of 48 cans of 7 ounces each with a total value of $1,918,633. Canneries were operated in five states and in Alaska. Table 131 contains a breakdown of the production.

TABLE 131. PRODUCTION OF CANNED SHRIMP.

State	No. of Canneries	Cases Packed	Value
Maine	6	3,003	$ 32,434
Georgia and Alabama	4	26,844	393,577
Mississippi	11	59,517	728,445
Louisiana	19	64,096	761,617
Alaska	1	91	2,560
Total	41	153,551	$1,918,633

Inspection. The shrimp-canning industry has developed a self-inspection service under the supervision of the U. S. Food and Drug Administration. Each canner requests the inspection; if his plant meets the standard requirements of arrangement, type of equipment, and facilities of sanitation, the request is granted. Under this service the raw shrimp are inspected when unloaded at the plant and prior to final shipment. If all conditions have been met, the cans may be labeled as being packed under the supervision of government inspectors. A few cents per case is added to the sale price of the shrimp in order to cover the costs of the service. About 90 per cent of the total pack is under this system of inspection, and it has done much to improve the quality.

Washing. When the shrimp are landed at the canning plant, they are unloaded into a washing tank. Jarvis (1943) gives the following description of the operation in a shrimp-canning plant:

"There are many minor differences in the mechanical setup of the apparatus used for washing and inspecting shrimp upon unloading at the cannery. Generally they are unloaded into a metal water tank, having a baffle plate fixed several feet from the end extending above and below the surface of the water. The shrimp sink and are carried under the baffle plate and out of the tank on a conveyor belt. The ice in which the shrimp may have been packed is held back by the plate. The shrimp then fall into a revolving drum or 'squirrel cage,' where they are tumbled about, removing surplus water and any bits of debris, such as seaweed; this is important as shrimp are bought by weight. In Alabama, Mississippi, and Louisiana some canners use wire-mesh belt conveyors or vibrating screens for this purpose.

"From the drum the shrimp are carried to the sorting conveyor, which is usually an endless belt of wire mesh, about 3 feet wide and 8 feet long, situated on a framework approximately 3 feet high. As the shrimp pass over this belt, they are sorted by employees who work under the supervision of a government inspector. Shrimp that are broken, torn, soft, discolored, or otherwise defective are removed. This is an inspection for freshness and condition of raw material only. Other grading factors are not considered.

"The shrimp fall from the end of a conveyor into a basket or metal lug box standing on platform scales. When the scales show a reading of 100 pounds net, the weight is checked, then noted down on tally sheets by a plant employee, and the government

inspector. Payment for the 'green' shrimp is usually based on the figures shown on the tally sheets.

"In Texas and on the Atlantic Coast the shrimp are iced down in refrigerator boxes or on the picking tables after being washed and inspected. This is done because the shrimp are landed at the cannery within an hour or two after catching and must be kept in ice several hours or they are not easily peeled. Shrimp landed at canneries in other areas have usually been held in ice long enough so that the shell is removed readily."

Picking. "As a rule the baskets or lug boxes of shrimp are taken directly from the inspection belt to the picking room, where they are 'picked' or 'peeled.' Shrimp are peeled entirely by hand, requiring a great deal of labor, as a satisfactory machine for this purpose has not yet been developed.

"In picking, the body portion of the shrimp is grasped with the left hand, with the legs pointing outward and the head extending beyond the thumb. With the right hand the picker seizes the head and breaks it off, then inserts the thumb of the right hand between the rows of legs, breaking open the shell and peeling off a section about 1 to 1½ inches long. A pressure of the left hand on the tail of the shrimp forces the meat from the remainder of the shell. If the workmanship of the individual pickers is not inspected, the tails are apt to be torn off in order to increase the rapidity of picking. Thus, the last segment of meat is lost, increasing the loss in weight and also lowering the quality. It is believed the amount of clear, red color in canned shrimp is associated with the presence of this tail segment, and decrease in amount of color makes the pack less desirable from the standpoint of grade.

"The picking room is entirely separated from the rest of the cannery, and the picking operation, like other steps in shrimp canning, shows evidence of improvement in handling. No two plants have exactly the same equipment and layout; but, generally the whole shrimp are emptied from the baskets or lug boxes onto long metal or metal-covered tables. These are about 25 feet long by 4 feet wide, usually sloping slightly from the sides toward the center, with each side divided into numbered spaces. A worker is assigned to each space and is given a corresponding number for identification. A metal flume is suspended above the middle of the table in some canneries, or the table may be constructed with built-in flumes running down each side.

"The shrimp meat is dropped into the flume by the pickers as soon as the hull is removed. The hulls are dropped into a numbered bucket by the side of each worker. The piecework payment wage depends on the number of buckets of hulls picked by the worker. This method eliminates the delay which has always occurred previously in shrimp canning, through holding the meats in 'cups' while picking. It also helps in washing the meats, and is considered so highly that it was made mandatory in 1938 for all shrimp canneries under federal inspection. Only those canneries not under inspection now pick the meat into cups.

"Standing by each picker is a cup of alum water, into which the hands must be dipped at frequent intervals as the shrimp heads contain digestive juices which have a corrosive effect on the skin unless this solution is used. A picker will peel from 100 to 400 pounds of shrimp a day, depending on the size of the shrimp and the skill of the individual. The loss of weight in picking averages from 50 to 55 per cent."

Preparation for Canning. *Washing.* "After the shrimp have been peeled and the meats inspected, they are emptied into a washer. This is of the flume type and is usually constructed with built-in riffles or turns, whereby the meats are shaken about more vigorously and the effectiveness of the wash is increased. This flume also acts as a conveyor. At the end of the washer is a perforated metal plate or table where the wash water is drained away and the meats are again inspected."

Blanching. "The 'brining' or 'presoaking' step has recently been abandoned by many packers. In theory it made the meats firmer in texture and was supposed to improve the color. This purpose is now accomplished by increasing the 'blanch' or 'precook.'

"The washed and drained meats are emptied into metal baskets, having a capacity of about 25 pounds. These baskets are lowered into a tank of boiling 50° salinometer brine. If the shrimp are to be canned 'wet pack,' they are blanched from 8 to 10 minutes, varying with size, or if preparing 'dry pack' shrimp, 10 to 12 minutes. At the end of the blanching period the baskets are raised by block-and-tackle and automatically dumped on a belt conveyor-drier.

"One packer uses a continuous blanch which consists essentially of a tank of boiling brine through which a conveyor passes. Wire baskets of shrimp are sent through the tank on this conveyor. The special features of this patented apparatus are the equipment for insuring uniform blanching.

"Wooden blanching tanks described in the literature are no longer used, nor is brine made by adding salt to water in the blanching tank. Wooden equipment is not permitted, and practically all packers now use a salt-dissolving apparatus. They manufacture brine in quantities and store it in tanks until it is needed. The brine used in blanching is now tested and brought to strength between each batch of shrimp. The tanks are emptied and filled with an entirely fresh brine after every seventh cook.

"Blanching is very important in determining the quality of the canned product. If the strength of the solution drops below 30° salinometer, the brine in the canned product may congeal, or 'jell.' Insufficient washing is also a factor in the congealing of canned shrimp during winter storage. Insufficient time in blanching may also cause jelling. If the brine solution is used for too many cooks or if too many shrimp are put in a basket, the brine will become 'ropy' and the shrimp will have a ragged appearance. If the brine is not kept boiling vigorously, the meats will link together. This means that they will not curl, and therefore cannot go through the mechanical grader. The trade demands a well-curled shrimp, and poorly curled shrimp are regarded as inferior. The loss in blanching or precooking is 45 per cent of the picked weight."

Drying. "Some of the driers are simply moving wire-screen belts, above which are fixed large fans of the paddle-wheel type. Others are enclosed by removable metal hoods, and the fans are of the blower type. The shrimp which move over the conveyor at the rate of about 11 feet per minute are cooled and dried by currents of air from these fans. Approximately 3 minutes are required to dry the surface moisture from the cooked shrimp. The fan drier also removes antennae, or 'whiskers,' and bits of shell. Drying is constant, with no variation in atmospheric conditions as was formerly the case. Therefore portable screen trays on which cooked shrimp were dried in the open are no longer used."

Inspection and Grading. "From the end of the drier the shrimp empty onto an inspection belt where they are scanned by several women who remove meats which are broken or otherwise unfit for canning. From the inspection belt the shrimp pass to the grader, which consists essentially of an inclined aluminum plate in which numerous holes are bored. It is divided into three sections. In the first the holes are ⅝ inch, in the second they are about 1 inch, while in the lowest they may be 1½ inches in diameter.

"When in operation the grader moves from side to side with a vibrating motion. The small shrimp fall through the holes at the top of the plate. The larger meats pass over the small holes, but fall through the larger holes near the bottom. The biggest shrimp, or 'jumbos,' fall over the end into a basket. Underneath each section of the plate is a metal chute with a double tray. The shrimp fall through the holes, down the chute, and into the trays. The filled trays are stacked in a rack nearby until sufficient shrimp of a size have been accumulated to justify packing that particular size or grade.

"The 'count' or number of shrimp filled into the can is the most important factor in grading. If the shrimp are to be packed as 'extra large' or 'jumbo,' the count to a standard No. 1 can should be 20 or less. 'Large' may run from 20 to 25, 'medium' from 25 to 40, and 'small' over 40. 'Pieces' must be graded thus or as 'broken' shrimp."

Filling. "The trays of shrimp are taken to metal-surfaced packing tables, having slotted spaces, just wide enough to hold a tray of shrimp. As a rule two girls work at each tray,

one filling the cans while the other adjusts them to the correct weight. No. 1 picnic (211 × 400) cans are used for the largest part of the pack. If 'wet-pack' shrimp are canned, the drained weight must be 5¾ ounces for this size container. It requires a fill of 5⅜ ounces of shrimp meat as there is a slight increase in weight during processing because of absorption of the brine.

" 'Dry-pack' shrimp in No. 1 cans are required to have a net weight of 5 ounces and are given a fill-in weight of 5⅛ ounces as there is a slight shrinkage in this method of processing. Cans for 'dry-pack' shrimp are usually lined with a one-, two-, or three-piece vegetable parchment paper liner. A three-piece liner may be placed in the can more readily than a one-piece liner. All cans are inside lined with 'C'-enamel, seafood formula. Other sizes of cans used commonly, together with the fill-in weights are: squat (307 × 400); 'wet pack,' 9¼ ounces and 'dry pack,' 9 ounces.

"The filling is watched by an inspector who removes occasional cans from the conveyor belt, checks the weights, empties out the contents, counts the number of shrimp to check the grade, and watches for evidence of poor workmanship, such as broken meats and bits of shell. In packing 'wet-pack' shrimp two methods are used in filling the cans with brine. In some establishments sprays of hot 2 per cent brine fill the cans as they pass along a conveyor belt to the closing machine. In other canneries a 50- to 75-grain salt tablet, the size varying with the container, is dropped into each can, which is then filled with hot water as it passes along the belt. The tablets may be added either by hand or from a mechanical dispenser."

Exhausting and Sealing. " 'Wet-pack' shrimp are sealed immediately by a closing machine operating at a speed of 60 cans per minute. As the cans are filled with hot brine, creation of a vacuum mechanically or by heat exhaust is regarded as unnecessary.

" 'Dry-pack' shrimp may be given a mechanical vacuum seal, or the cans may be sealed cold, without heat exhaust or mechanical vacuum. Vacuum-packed shrimp are regarded to be of superior quality, have a better color and flavor than nonvacuum packs, and constitute about 75 per cent of the production of 'dry-pack' shrimp. Regulations of the U. S. Food and Drug Administration require a vacuum of not less than 12 inches in the can after processing if it is to be labeled vacuum pack. The same process is given as for a nonvacuum pack. The process is shorter only if the cans are sealed with a vacuum in excess of 25 inches."

Processing or Retorting. "The sealed cans are stacked in retort baskets which hold about 640 No. 1 cans. A retort has a capacity of either 2 or 3 baskets. 'Retorting' or 'cooking' is controlled closely under the inspection regulations, which also specify process times and temperatures. 'Wet-pack' shrimp in No. 1 or squat cans are processed 20 minutes at 240° F (115.7° C) (10-pound pressure), or 10 minutes at 250° F (121.1° C) (15-pound pressure). No. 1½ cans are processed for 23 minutes at 240° F (115.7° C), or 12 minutes at 250° F (121.1° C). 'Dry-pack' shrimp in No. 1 or squat cans are processed 85 minutes at 240° F (115.7° C), or 60 minutes at 250° F (121.1° C) if the can is lined with a one-piece parchment liner. If there is no liner or if a three-piece liner is used, the process is 70 minutes at 240° F (115.7° C), or 53 minutes at 250° F (121.1° C). While processing at 240° F (115.7° C) is permitted, the use of a 250° F (121.1° C) process is recommended as the better canning practice."

Cooling and Washing. "At the end of the processing period the cans are water-cooled to a temperature of 98° F (36.7° C) before they are stacked in the warehouse. Canned shrimp may be cooled in special tanks or in retorts. In the more up-to-date canneries, or in the great majority of cases, the pack is cooled in retorts. In canning 'wet-pack' shrimp cooling in the retorts aids in preventing overcooking and softening, while in 'dry-pack' shrimp it aids mechanically in pushing the can ends back in place, that is, where a nonvacuum seal is used. Alkaline solutions are not required in cleaning shrimp cans after processing."

Storing, Labeling, and Shipping. "Shrimp are usually held about 48 hours before labeling and casing. Conditions of labeling, storage, and shipping are specified in the inspection regulations. All inspected cans are now coded so that any lot may be identified. No lot or code may be labeled until it has been examined and passed by the inspector. In addition the thermometer chart must be checked to determine sufficiency of cook and each cook must be identified with the corresponding code mark and date. The packer is required to keep these records at least 1 year. A standard case of canned shrimp contains 48 No. 1 picnic cans.

"Any labels used for inspected canned shrimp must be approved by the U. S. Food and Drug Administration; this ruling applies to canned shrimp only and not to other canned products. Such labels may bear the statement 'Production supervised by U. S. Food and Drug Administration,' which may not appear on uninspected canned shrimp or on shrimp intended for export. Both labeling machines and hand-labeling are used in labeling the cans. Each lot or 'code mark' is stored and must be held separate. No lot may be shipped until the inspector issues a certificate to the packer, stating that the parcel complies with all regulations."

Shrimp Packed in Glass. "An increasing amount of shrimp is being packed in glass. Only the best color grades in the larger sizes are packed in glass since appearance is the principal sales appeal factor. The method of handling the shrimp is identical with packing in tin up to and including filling.

"Several sizes of glass containers are used; but the most common are 8-ounce tumblers, with a drained weight of 5¼ ounces and a fill-in weight of 5 ounces, and the 9-ounce tumbler, which holds 6¾ ounces drained weight and 6⅛ ounces fill-in weight. If the containers are overfilled, 'jelling' occurs, while 'slack-fill' shrimp soon present a ragged, unattractive appearance. Other containers used are a tumbler holding 2½ ounces, packed principally for the English market, and a 'nappy' jar for 'cocktail' shrimp, filled in rosette style. The containers are filled with a 3 per cent brine, filled hot at temperatures varying from 160 to 180° F (71.1 to 82.2° C). The jars are sealed in a glass-pack vacuum-closing machine under a vacuum of not more than 20 inches. Higher vacua cause ebullition with loss of brine.

"The sealed containers are placed in retort baskets with a rubber mat between each layer. Mats protect the enamel lids against fading, scratching, or blistering during processing. The process times specified for glass containers under inspection regulations are 5 to 9 ounces inclusive, 22 minutes at 240° F (115.7° C) (10-pound pressure), or 14 minutes at 250° F (121.1° C) (15-pound pressure).

"The pack is cooled in the retort under pressure so that the lids will not be blown off the jars. The cooling water is first admitted at a temperature of 190° F (87.8° C) until the retort is one-fourth full; then at 170° F (76.7° C) until the half-way mark is reached; and finally at 140° F (60° C) until it is three-fourths full, when the temperature is dropped to 100° F (37.8° C). When the retort is full, water runs through at a normal temperature or at from 60 to 70° F (15.6 to 21.1° C), for about 10 minutes. The entire cooling process requires about 35 minutes.

"After cooling, the containers are dried, labeled by hand, and packed in corrugated fiberboard cartons, 2 dozen jars to a carton. Glass-pack shrimp are very attractive as a display product, but the retailer should be warned that the glasses must not be left long in a strong light as the shrimp may then become 'light-struck.'"

Packing for Freezing

When the shrimp have been graded, they are placed in 1-, 5-, or 10-pound waxed cartons for freezing. The 1-pound size is marketed for family consumption and the larger sizes go to hotels and restaurant trade. Some of these are fitted inside with a liner of some wrapping material, which is further protection against

oxidation and loss of moisture while the shrimp are in cold storage. In others the cartons have several holes in the bottom approximately a half inch in diameter. After the freezing is completed, the cartons are immersed in cold water and quickly removed. The frozen shrimp cause a glaze of ice to form on their surfaces,

(Courtesy of Atlantic Coast Fisheries Co.)

FIG. 28–3. A package of frozen shrimp.

giving them a protective coating, and the surplus water drains from the carton through the holes in the bottom.

Some plants pack shrimp in metal pans designed for freezing. They may contain up to 30 pounds, but are usually of 5- and 10-pound capacity. The shrimp are packed tightly in the pan and frozen, after which the block is removed and glazed by dipping in cold water, or the spaces between the shrimp filled with cold water. The shrimp are then frozen in a block. This method reduces evaporation of water from the shrimp to a minimum during the freezing period.

After the blocks of frozen shrimp are removed from the pans, they are packed in cartons or wooden boxes of 100- to 150-pounds capacity; these are lined with protective wrapping material or cellophane. They are then stored for future shipment or may be shipped immediately to distribution points throughout the country.

There are a few continuous freezers in operation in the shrimp industry; these are designed with a horizontal moving metal belt of woven or stainless steel wire. The freshly washed shrimp drop onto the belt as they come from the washer and are carried through an insulated box fitted with freezer coils. The speed of the belt is so regulated that the shrimp freeze individually while passing through the low temperature of the box. At the discharge end the frozen shrimp are weighed into cartons containing 30, 40, or 50 pounds and, in a few instances, 100 pounds. The cartons are lined with a protective material or closely fitting bags. When the

carton is filled with the necessary weight, it is sealed and placed in the storage room until shipment.

Within the past few months a package of frozen shrimp, known as "Fan Tail," has been marketed. These shrimp are shelled, except for the tail fin; they are rolled in batter of various ingredients and frozen ready to French fry in deep fat. They are packed in 1-pound waxed cartons, having a cellophane window, and are very popular.

Freezing Cooked Shrimp

Some of the peeled or shelled shrimp are cooked before freezing. The shrimp are cooked in kettles or vats fitted with steam coils and containing a brine solution. In different establishments the strength of the solution varies between 5 to 10 per cent salt; there is also a variation in the time of cooking. A brine solution of 15 per cent strength has been recommended for this purpose by some who have investigated this method of preparing shrimp for freezing, but unless the cooking time is reduced accordingly, deterioration in storage is more rapid. After cooking, the shrimp are quickly cooled and packed in cartons of various size. The cartons of frozen cooked shrimp are either stored for future market or are immediately shipped for distribution.

If the storage period of frozen cooked shrimp is prolonged, they become tough and fibrous, generally deteriorating in quality. It is suggested that the cooking time be held to a minimum, or until the meat is pink-colored and firm enough to be handled. A time limit of not more than 4 minutes in boiling brine is suggested. Immediately after the cooked shrimp are removed from the brine, they should be immersed in cold running water so that the cooking or blanching will stop. If the brine bath is prepared in the early morning for use throughout the day and is kept at a boiling temperature throughout the period of operation, a considerable amount of water will evaporate. This will cause a constant increase in the brine strength during the day. As a result those shrimp cooked in the early morning will be of a different quality than those cooked just before operations have ceased for the day. This can be remedied by checking the brine strength with a salinometer at hourly intervals during the day and adding sufficient water to compensate for the water lost through evaporation.

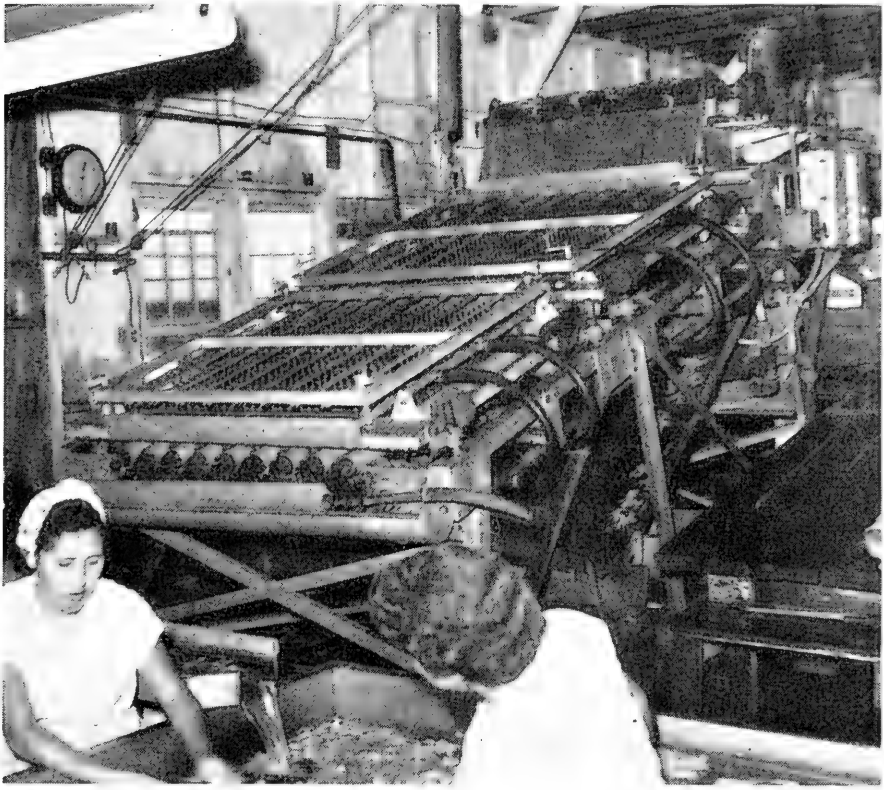
After cooling sufficiently they can be packed in various type packages and placed either in a cooler or immediately in the freezer. A sealed moisture-vapor-proof container is the best type package for shrimp. If these are not available, then the shrimp should be either glazed in blocks or individually by dipping in cold water immediately after freezing.

The storage period for frozen cooked shrimp should not be longer than a month. When stored longer than this, denaturation has progressed far enough for the quality to be adversely affected. They become tough and a loss of flavor occurs.

Shrimp-Peeling Device

Within the last year a mechanical device for separating the meats from the shell has been put into operation. The essential part of the machine is two sets of soft rubber rollers. One set of them is driven by a motor, while the second is operated by friction.

The rollers are inclined at an angle of about 15° so that the shrimp fed into one end are carried by gravity toward the discharge end. A series of several hundred rubber-tipped springs operate with a vertical motion against the rollers.



(Courtesy Southern Fisherman)

FIG. 28–4. The shrimp peeling machine has only recently been put into operation. It is reported to be much more efficient than the hand method.

When the shrimp pass along the rollers, these rubber-tipped springs gently massage them against the revolving rubber rollers. This gradually loosens the shell, which is finally caught between the rollers as they revolve and is pulled off between them. The shrimp meat is too large to become caught between the rollers and is carried toward the discharge end of the machine.

It is stated that the machine recovers between 10 and 15 pounds more meat per barrel of shrimp than is possible with hand pickers. A patent covering the machine has been applied for.

Drying

Sun-dried shrimp were first prepared in Louisiana in 1873, when the Chinese began to immigrate to the Barataria Bay region of that state. The production of dried shrimp in 1948 was 1,233,199 pounds, valued at approximately $690,000.

It is marketed in San Francisco and other cities having a large oriental population. Formerly, China imported large quantities of it; of late years this export trade has been considerably curtailed.

Large wooden drying platforms, made of cypress wood, are erected near the water's edge. They are built on posts standing 8 or 10 feet above ground for better air circulation. One of the largest platforms on the bay is 230 feet long by 180 feet wide and has a capacity of about 1,000 baskets or 100,000 pounds of green shrimp at a time. The floor of the platform, instead of being level, is gently undulating, having an ocean-wave effect, the waves being about 2 feet in height with about 30 feet between crests. A small crack is left between each board which facilitates drying.

The shrimp are brought directly to the drying platform by the fishing boats, where they are unloaded and washed and placed in large copper kettles. To each kettle of water from 10 to 20 quarts of salt are added, depending on the weather; in damp weather more salt is required than in dry weather. After the water has been brought to a boil, the shrimp are dumped in, about 900 pounds to each kettle. They are then boiled for ½ to ¾ of an hour. The method of judging whether the shrimp have been boiled long enough is to hold one up to the light and note the shrinkage of meat within the shell. A clear space of about ¼ of an inch between the back and the meat indicates sufficient cooking. Before each boiling the same quantity of salt is added to the water; and after the fifth or sixth boil the water in the kettle is entirely renewed and the process repeated.

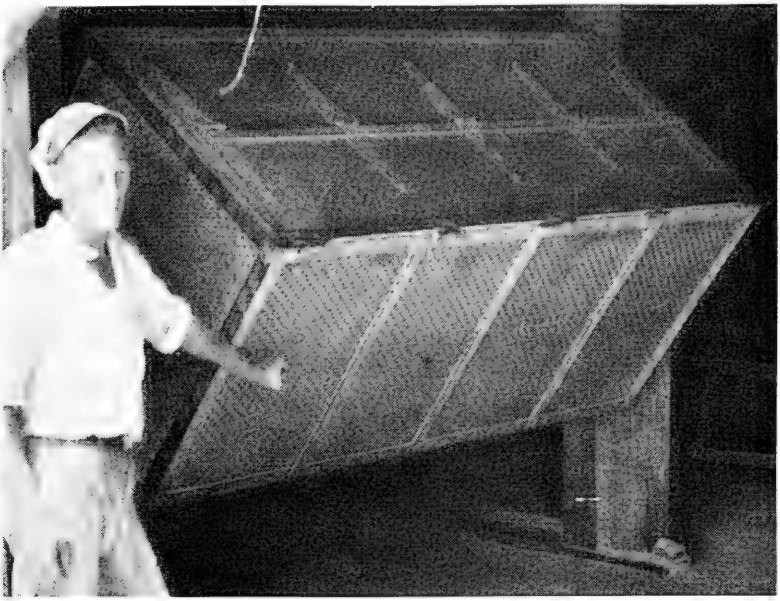
When the shrimp have been boiled for a sufficient length of time, they are dipped from the kettles into wheelbarrows or carts by means of a large dip net. After draining for about 15 minutes they are hauled to the drying platform. Workmen spread them out with long wooden rakes in a thin layer, not more than 2 or 3 inches thick. The thickness of the shrimp on the platform depends upon the quantity on hand at any one time, and they are never spread on the platform to the maximum depth unless the amount of shrimp on hand makes it necessary. Several times each day the shrimp are worked over with rakes to facilitate drying. The frequency with which the shrimp are turned during the day depends upon the thickness of the layer. If they are 3 inches thick, turning is required about every 20 minutes.

Every night the shrimp are pushed and swept onto the ridges of the platform in long windrows. A-shaped trusses are placed astride each windrow of shrimp and covered with tarpaulins to keep off rain and dew. The tarpaulins must be so placed as to provide an opening at each end of the windrow to allow perfect ventilation, otherwise the shrimp would become heated and spoil. If the drying process is sufficiently well advanced, the trusses may be dispensed with and the tarpaulins spread directly over the shrimp; but in the earlier stages ventilation is absolutely indispensable and the trusses must be used.

If the weather is good, the drying process can be completed in 1 or 2 days, depending somewhat on the thickness of the shrimp on the platform. If it should rain, the shrimp are pushed onto the ridges and covered with tarpaulins. No matter how hard it rains, they will not get wet since the falling water drains away from the ridges. When the sun comes out, the shrimp are again spread out and the drying process continued. However, a long period of wet and cloudy weather frequently catches the men with a platform full of shrimp which are still quite

green and often spoil before favorable weather returns. But if the drying process is well advanced before being interrupted by rainy weather, the shrimp can be stored in the warehouse and kept for many days. They may be brought out on the platform and the drying completed upon the return of clear weather.

A small quantity of shrimp are dried without being previously cooked in brine (Johnson and Lindner, 1934). The fresh shrimp are laid in wire trays and mashed



(Courtesy U. S. Fish and Wildlife Service)

Fig. 28–5. In former days "dancing the shrimp" to remove shells was labor and not a pastime. It has been replaced for shelling dried shrimp by this mechanical huller.

with a mallet. The trays of shrimp are then put out in the sun to dry. This product brings a higher price in the market than those dried after cooking in brine.

Until about 1925 the heads and shell of the dried shrimp were separated from the meats by "dancing." This was the term given to the tramping of the shrimp by laborers, whose shoes were covered with cloth or socks. The tramping motions were synchronized with a spontaneous "chant," thus the term "dancing."

Today the meats are mechanically separated from the waste material. The mechanical device is either a rectangular box or barrel-like arrangement covered with coarse screen or perforated metal. The revolving of these devices tumbles the shrimp, and the waste particles drop through the screen and are thus separated from the meat. The meat is usually packed in sugar barrels, which will hold about 230 pounds. A basket of green shrimp weighing 105 pounds will produce 12 to 14 pounds of the dried product.

Shrimp "Bran." This is a dried waste material which contains the shell, heads, and legs. During the serious shortage of poultry and stock feed in recent years there has been a considerable demand for shrimp "bran." Various investigators

have shown that it is valuable as an ingredient in mixed poultry and stock feeds. Manning (1934) gave the following partial analysis of this material:

	%
Moisture	9.00
Crude protein	54.51
Crude ash	18.03
Ether extract	2.86
Undetermined	15.60

REFERENCES

Anon., "Shrimp-Peeling Machine," *Southern Fisherman,* **9,** No. 11, 33 (1949).

Anderson, W. W., and Lindner, M. J., "A Provisional Key to the Shrimps of the Family *Penaeidae,* with Special Reference to American Forms," *Trans. Am. Fisheries Soc.,* **73,** 284–319 (1943).

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest,* **18** (1949).

Atwater, W. O., "The Chemical Composition and Nutritive Values of Food Fishes and Aquatic Invertebrates," *U. S. Fish Comm. Rept.,* **1888,** 679 (1892).

Burkenroad, M. D., "Further Observations on *Penaeidae* of the Northern Gulf of Mexico," *Bingham Oceanographic Collection Bull.,* **6,** Art. 6, 1–62 (1939).

Chapman, A. C., "On the Presence of Compounds of Arsenic in Marine Crustaceans and Shellfish," *Analyst,* **51,** 548 (1926).

Coulson, E. J., "Chemical Composition of Conch Meat," U. S. Bureau of Fisheries, *Special Memo.,* **2065–B** (1935).

Fieger, E. A., Green, M., Lewis, H., and Kaloyereas, S., "Quality Control Tests for Shrimp," *Frozen Food Industry and Locker Plant J.,* **3,** Nos. 9–10, 1 (1947).

Fieger, E. A., and DuBois, C. W., "Conditions Affecting Quality of Frozen Shrimp," *Refrig. Eng.,* **52,** 225–228 (1946).

Green, M., Holmes, D., and McCleskey, C. S., "Bacteriology of Shrimp," *Food Research,* **14,** 365–404 (1949).

Jarvis, N. D., "Principles and Methods in the Canning of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.,* **7,** 275–283 (1943).

Johnson, F. F., and Lindner, M. J., "Shrimp Industry of the South Atlantic and Gulf States," U. S. Bureau of Fisheries, *Investigational Rept.,* **21** (1934).

King, J. E., "A Study of the Reproductive Organs of the Common Marine Shrimp, *Penaeus setiferus* (Linnaeus)," *Biological Bull.,* **94,** 244–262 (1948).

Lee, C. F., and Nilson, H. W., "Study of the Metabolism of Naturally Occurring Fluorine in Canned Salmon and Mackerel," U. S. Bureau of Fisheries, *Investigational Rept.,* **44** (1939).

Lindner, M. J., "Suggestions for the Louisiana Shrimp Fishery," New Orleans, Louisiana, Louisiana State Department of Conservation, 1936.

Manning, J. R., "Value of Shrimp Meal," U. S. Bureau of Fisheries, *Memo.,* **S–328** (1934).

Newell, J. M., and McCollum, E. V., "Spectrographic Analysis of Marine Products," U. S. Bureau of Fisheries, *Investigational Rept.,* **5** (1931).

Nilson, W. H., and Coulson, E. J., "The Mineral Content of the Edible Portions of Some American Fishery Products," U. S. Bureau of Fisheries, *Investigational Rept.,* **41** (1939).

Pearson, J. C., "The Early Life Histories of Some American *Penaeidae,* Chiefly the Commercial Shrimp, *Penaeus setiferus* (Linnaeus)," U. S. Bureau of Fisheries *Bull.,* **49,** No. 30, 1–73 (1939).

Pottinger, S. R., and Baldwin, W. H., "Percentage of Certain Essential Amino Acids in Fish and Shellfish," *Sixth Pacific Science Congress, Proc.*, 453 (1939).

Stansby, M. E., "Composition of Fish," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **116** (1947).

Weymouth, F. W., Lindner, M. J., and Anderson, W. W., "Preliminary Report on the Life History of the Common Shrimp, *Penaeus setiferus* (Linnaeus)," U. S. Bureau of Fisheries *Bull.*, **48**, No. 14, 1–26 (1933).

CHAPTER 29

The American Crab Industry

Introduction

While the crab industry is one of the youngest in all the fisheries, its popularity among consumers is almost universal. This can be attributed to the development shortly after 1875 of refrigerated transport to the interior sections of the United States. It was about this time that soft crabs were first shipped from Crisfield, Md. Formerly, the unfamiliarity of the majority of sea food consumers with this shellfish retarded the market. The annual production of crabs in the Chesapeake Bay area reached more than 3 million pounds in 1880; by 1890 this had about tripled. It has continued to rise almost every year until in 1945 it was almost 38 million pounds, valued at almost 3½ million dollars.

When the demand continued to increase more rapidly than could be supplied by one area, the industry spread both north and south along the Atlantic and

TABLE 132. STATISTICS ON THE PRODUCTION OF CRABS BY STATES.

Blue Crabs.

	Hard		Soft and Peelers	
	Pounds	Value	Pounds	Value
Connecticut	3,900	$ 509	300	$ 122
New Jersey	603,100	47,872	500	175
Delaware	1,248,300	150,000	3,000	1,000
Maryland	25,568,300	1,190,524	3,010,200	763,585
Virginia	34,333,600	1,721,719	2,442,800	611,250
North Carolina [1]	2,364,100	72,125		
South Carolina [1]	3,566,100	96,630		
Georgia [1]	6,483,600	189,530	2,000	480
Florida [1]	2,207,400	110,370		
Alabama [1]	5,638,600	282,030		
Mississippi [1]	31,279,900	1,418,260	2,369,700	1,706,256
Louisiana [1]	339,200	39,131		
Texas [1]	5,696,400	284,820	184,300	55,290

[1] The statistics for these States are for 1945; all others are 1947.

Rock Crabs.

	Pounds	Value
Maine	320,100	$ 16,136
New Hampshire	18,000	270
Massachusetts	2,072,200	115,000
California	15,200	1,628

TABLE 132. STATISTICS ON THE PRODUCTION OF CRABS BY STATES.—*Continued.*

Stone Crabs (1945 production).

	Pounds	Value
Florida	133,400	$ 45,435

Dungeness Crabs.

	Pounds	Value
Washington	11,973,200	$1,080,998
Oregon	7,531,700	655,259
California	10,733,400	1,304,918
Alaska [1]	2,438,600	131,436

[1] The Alaska statistics are for the year 1946; all others are 1947.

King Crab, 1948 Production.

	Pounds	Value
Alaska	2,133,354	$ 96,001

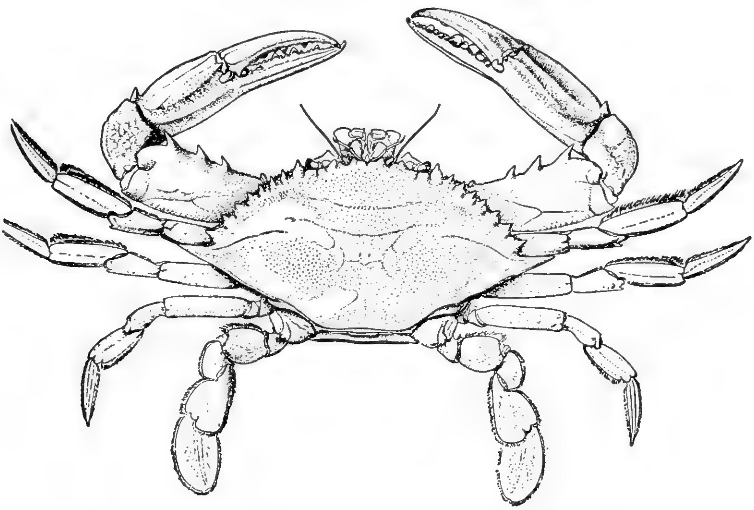
Source: U. S. Fish and Wildlife Service.

Gulf coasts. Supplies of crab meat can always be found in the sea food markets of the large interior cities, and soft crabs are available in season.

The latest statistics relative to the production of crabs by states is presented in Table 132.

Species of Economic Importance

The blue crab (*Callinectes sapidus*), commercially the most important American crab, is found on the Atlantic Coast from Massachusetts Bay to at least as far south as the northern part of South America. It is common along the United



(Courtesy U. S. Fish and Wildlife Service)

FIG. 29–1. The blue crab of the Atlantic and Gulf Coasts is one of the most popular of seafoods.

States Coast from Massachusetts to Texas, and is especially abundant in bays and at the mouth of rivers. Although its natural medium is salt water, it is sometimes found in brackish and even fresh water.

The dungeness (*Cancer magister*) is the common crab of the Pacific Coast; it is found from Lower California to Unalaska. Its favorite habitat is in shallow water, on exposed sandy beaches, or in sandy bays.

The rock crab (*Cancer irroratus*) is most common on the New England Coast, but it is found from Labrador to South Carolina. This crab is not fished extensively although it is exceedingly abundant, contains more meat than the blue crab, and is equal to the latter in flavor. Rock crabs are caught to some extent in all the New England states.

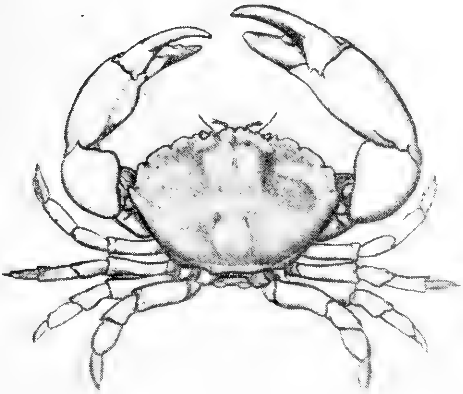
The Jonah crab (*Cancer borealis*) resembles the rock crab, but it has a rougher shell with scalloped edges and is usually slightly larger. It is found from Long Island to Nova Scotia, the principal localities being Noank, Connecticut; Narragansett Bay and off Watch Hill, Rhode Island; Vineyard Sound, No Man's Land, and Salem, Massachusetts; Casco Bay, Maine; and the Bay of Fundy, Nova Scotia. It ranges in size up to about 6 inches across the shell. Its flavor is excellent, but it has never been an important article of commerce because of its limited distribution.

The stone crab (*Menippe mercenarius*) ranges from North Carolina to Texas. It compares favorably in flavor with the blue crab and also grows to a much larger size than the blue crab. The principal fisheries are in Charleston, South Carolina, and Key West, Florida, but are not extensive because of the scarcity of this crustacean.

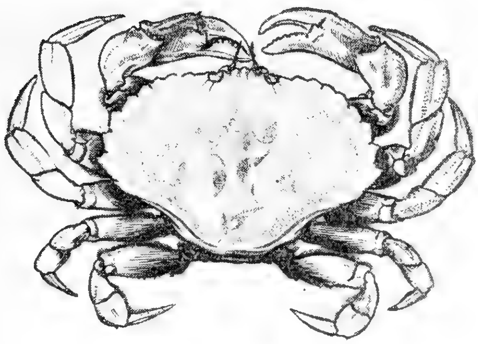
The king crab (*Lopholithodes mandtii*) is found on the Pacific Coast, but is now rare.

A list of crabs of minor importance is given below:

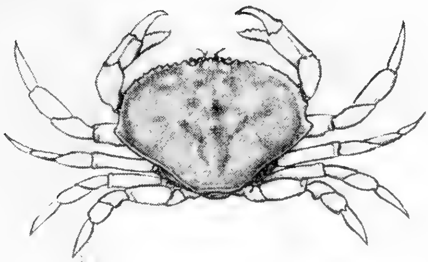
Fiddler crab	*Gelasimus pugnax*
	" *pugilator*
	" *minax*
Green crab	*Carcinus maenas*, Leach
Hermit crab	*Eupagurua bernhardus*
	" *pollicaris*
	" *longicarpus*
Horseshoe crab	*Limulus polyphemus*
Jonah crab	*Cancer borealis*
Kelp crab	*Epialtus productus*
Lady crab, sand crab, squeaker crab	*Platyonichus ocellatus*, Latr.
Mud crab	*Panopeus herbstii*, Edwards
Mussel crab	*Pinnotheres maculatus*
Oyster crab	*Pinnotheres ostreum*
Purple shore crab	*Heterograpsus nudus*
Red crab	*Cancer productus*
Sand bug	*Hippatalpoida*, Say
Spider crab	*Libinia emarginata*, Leach
	" *dubia*, Edwards
Yellow shore crab	*Heterograpsus oregonensis*



The stone crab of Florida.



The rock crab of New England.



The dungeness crab of the Pacific Coast.

Fig. 29–2. Three species of crabs which are preferred in certain localities.

Alaska King Crab

The Alaska king or Japanese crab is the term applied to the genus *Paralithodes*, made up of 3 species: *P. camtchatica, P. brevipes,* and *P. platypus.* Although the canned Japanese crab pack contained about 8 per cent of 2 additional species, these are not found in Alaskan waters. The crabs are located both north and south of the Aleutian Islands, but the greatest populations are in the Bering Sea to the north. These are, by far, the largest crabs, averaging about 12 pounds in weight and from 3½ to 4 feet from tip to tip of the legs. The carapace is small in comparison to the legs, which often results in its being referred to as the "spider crab"; this is incorrect as the "spider crab" is entirely different and unfit for food. The carapace measures between 7 and 9 inches, and is covered with spines, the number of which are employed as a means of species identification.

This group of crabs grows very slowly and requires 9 to 10 years before reaching sexual maturity. They inhabit cold water on a mud and sand bottom at a depth of from 100 to 125 fathoms, where the temperature ranges from 35 to 50° F (from 3 to 10° C). In 1939 Japanese canners exported about 55 per cent of their pack to the United States; from 1924 to 1941 this amounted to a total of 3,288,997 cases of 48 1-pound cans.

Composition

Feller and Parks (1926) found the composition of the Japanese or Alaska king (*P. camtchatica*) and dungeness crab meat to be as follows:

	Japanese	Dungeness
	%	%
Moisture	77.65	80.98
Protein	17.54	15.52
Fat	2.58	1.82
Ash	1.53	1.69
Iodine	362 pp million	102 pp billion

Life History of the Blue Crab

The young of the blue crab (*Callinectes sapidus*) are hatched from very small eggs which are attached during incubation to small hairs on the inner branches of the swimmerets on the under side of the abdomen of the female. The eggs are yellow or orange when first laid and become almost black as hatching time approaches. The entire large yellowish mass of eggs is called a sponge and contains from 1,750,000 to 2,000,000 eggs, each about 1/100 of an inch in diameter. These eggs hatch after about 15 days' incubation. After hatching, the young crabs pass through 2 free-swimming stages. During the first stage the young crab is known as a zoea and little resembles the adult. The body is somewhat cylindrical in shape, the eyes are large and conspicuous, and the spines at the sides are short; there is a long curved spine on the back and the claws are lacking. The zoea has a long sharp beak, 2 pairs of antennae, and 4 pairs of leglike appendages. During this stage the young crab moults about 6 times. In the second stage the young crab is known as a megalops. The megalops more nearly resembles the adult, having a rather flattened body and a shorter and wider abdomen than the zoea.

During this stage it swims freely, but may also walk on the bottom. The megalops does not moult, except to assume the true crab shape.

In passing from the megalops stage to the adult crab stage the crab moults about 15 times at intervals averaging approximately 15 days. During this period it increases from $\frac{1}{25}$ of an inch in width to about 7 inches, expanding about $\frac{1}{3}$ at

(*Courtesy U. S. Fish and Wildlife Service*)

FIG. 29–3. The blue crab sheds its old shell. Even when partially out its size is noticeably larger than the old shell.

each moulting. Growth is rapid, and the crabs mature and mate at the age of 12 to 14 months during the second summer. Mating occurs in the female at the time of the last moulting while she is still soft. She is carried tightly by the male for a few days prior to such moulting, and at this stage "doublers" or mating crabs are often caught on the trotlines. If mating occurs early in the summer, the eggs are laid about 2 months later; when the mating occurs in July or August, the eggs are not laid until the following spring or summer. The female crab may lay 2 or more batches of eggs during her lifetime. Most crabs live only 3 years although a few survive for 4 years.

Young crabs possess the power of regenerating a leg or claw lost or voluntarily thrown off. The regeneration is completed at moulting.

Blue crabs are scavengers and cannibals although they occasionally feed upon aquatic vegetation; their favorite food, however, is the flesh of dead and putrid animals.

In winter most of the crabs retire to fairly deep water. Formerly, it was thought that they buried themselves in the muddy or sandy bottoms in the deeper parts of bays and harbors, but it is now believed that most of them do not bury themselves, but remain more or less inactive on the bottom.

Atlantic Coast Fishery

Location. Commercial crab fisheries exist in every state along the Atlantic and Gulf coasts. However, in Maine, New Hampshire, Rhode Island, and Connecticut the industry is of only minor importance. The center of the blue-crab industry, which is the major crab industry in the United States, was formerly on Chesapeake Bay. Of late years the total production in the States bordering the Gulf has surpassed that of Maryland and Virginia. Chesapeake Bay still leads in the production of soft crabs. Louisiana alone produced over 33,000,000 pounds of crabs in the year 1945.

Seasons. *Soft Crabs.* Soft crabs are taken only during the warm months as the moulting of the young at successive stages of growth occurs during warm weather; therefore, the soft-crab season extends through the late spring, summer, and early fall. The season opens 2 or 3 weeks earlier in Virginia waters than in Maryland, the exact date depending upon the weather. In early springs soft-crabbing in Virginia begins during the latter part of April. It is discontinued in Virginia about the first of August because of very hot weather and poor transportation facilities. However, at Crisfield, Md. soft crabs are caught as late as the first or the middle of October.

Hard Crabs. During cold weather trotline crabbing is not practiced as the cold water chills the crabs into numbness and inactivity, and they do not seize the bait

TABLE 133. COMPOSITION OF THE EDIBLE MEAT OF THE BLUE CRAB AND SAND CRAB.

Determination	Blue Crab		Sand Crab	
	Moist Basis %	Dry Basis %	Moist Basis %	Dry Basis %
Moisture	79.04		76.28	
Dry matter	20.96		23.72	
Total ash	2.15	10.28	1.77	7.45
Crude protein ($N \times 6.25$)	17.95	85.62	20.28	85.49
Ether extract (fat)	0.39	1.86	0.24	1.03
Carbohydrate (diff.)	0.47	2.24	1.43	6.03
Alkalinity of ash	11.65	55.60	12.87	54.30
Cal per 100 gm (Sherman)	77.2		89.8	
Potassium	0.188	0.897	0.153	0.734
Calcium	0.133	0.635	0.134	0.639
Magnesium	0.012	0.057	0.008	0.039
Phosphorus	0.038	0.182	0.047	0.119
Iron	0.0020	0.0094	0.0015	0.0071
Copper	0.0013	0.0061	0.0012	0.0055
Iodine (ppb)	322	1,585	464	2,215
Manganese	trace		trace	

Source: Watson, V. K., and Fellers, C. R., "Nutritive Value of the Blue Crab (*Callinectes sapidus*) and Sand Crab (*Platyonichus ocellatus*, Latreille)," *Am. Fisheries Soc. Trans.*, 65, 342–349 (1935).

and hang on as the line is raised. In winter months fishing is done with dredges and traps which can be handled in deeper waters. Legal sizes, varying somewhat from season to season and between states, have been established by some states. Generally the legal lengths are: hard crabs, 5 inches; peelers, 3 inches; and soft crabs, 3½ inches. Crabbers often carry a small measuring stick.

Methods of Fishing. *Soft-Shell Crabs.* The soft-crab fishery is necessarily limited to late spring, summer, and early fall since soft crabs are obtained only as a result of the moulting of the young crabs, which takes place during the warmer months. Soft crabs are either caught in that condition, or are obtained by holding a "peeler," which is a crab about to shed, until it moults. When a crab approaches the time of moulting, a narrow white line appears on the outer margin of the next to the outer segment of the fourth pair of legs or "back fins." In this stage the crab is called a "fat," "green," or "snot" crab. It is not saved with the catch as it would be likely to die before moulting. Within a few days the line becomes pink in color and the crab is known by the crabbers as a "peeler." Peelers are saved and kept alive in live boxes and floats until they moult. The bulk of the soft crabs handled are obtained by the "shedding out" of peelers or crabs about to shed.

Soft crabs and peelers are chiefly caught in dip or push nets or in scrapes although a few are caught on the trotlines. Trotlines are used mainly for the catching of hard crabs since a soft crab cannot take the bait and peelers do not often bite as they eat little for a few days before they shed.

A dip net is a ¼-inch iron rod hoop about a foot in diameter, carrying a net bag of 1-inch mesh attached to a straight wooden handle about 7 feet in length. It is used by crabbers fishing in the shallow waters of coves, inlets, mouths of creeks, and other places where the bottoms are unsuitable for the use of the scrape. The crabber, reaching into the water from a boat, scoops up the soft crabs or peelers.

The push net is similar to the dip net, with one exception: The iron ring of the push net is about twice as large and flattened on the side opposite the handle where it comes in contact with the bottom. This net is pushed along the bottom by the crabber, who wades in the eel grass where soft or peeler crabs often hide while the new shell hardens. The net usually gathers up trash of all kinds as well as soft crabs. The soft crabs and peelers are separated from the refuse as they are unloaded. They are then placed in a live box or skiff towed along by a rope usually tied around the waist of the crabber. The catch with the push net is about the same as that with the dip net.

A scrape consists essentially of a triangular iron frame, with a base varying in width from 2 to 5 feet attached to a cotton-mesh bag which extends about 6 feet behind. The scrape is similar to the oyster dredge, except that it is lighter, has no teeth on the front bar, and has a cotton instead of a chain bag. The scrape is dragged by a rope fastened to the apex. Small sailboats, varying in length from 20 to 60 feet, are commonly used for this method of crabbing. Generally, 1 scrape is dragged on each side of the boat, but the larger boats use 3 and sometimes 4 scrapes. They are hauled in alternately by hand after covering 75 to 200 yards, and the contents are dumped into shallow boxes attached to the side of the boat from which the crabs are sorted out of the mass of seaweed, shells, fish, etc. The hard crabs are put into barrels and the soft crabs are kept in boxes.

Two men are required to handle a heavy scrape, but the lighter scrapes are

drawn up by a single man. With a good breeze a 2-man crew can handle 2 light scrapes. In order to obtain good catches of crabs the scrape must be dragged over the bottom slightly faster than the crabs can travel so that they cannot escape when once in the bag.

The crabber usually reaches the crabbing grounds at daybreak and returns to market his catch before noon; it is advantageous to sell the crabs before the heat of the day has injured those confined in the live boxes.

Since the practice of scraping is carried on in fairly deep water and is confined to the Crisfield, Md., region, where the immature crabs predominate during the season, the bulk of the catch consists of peelers. As the crabs move inshore just before shedding, soft crabs are more numerous in shallower waters.

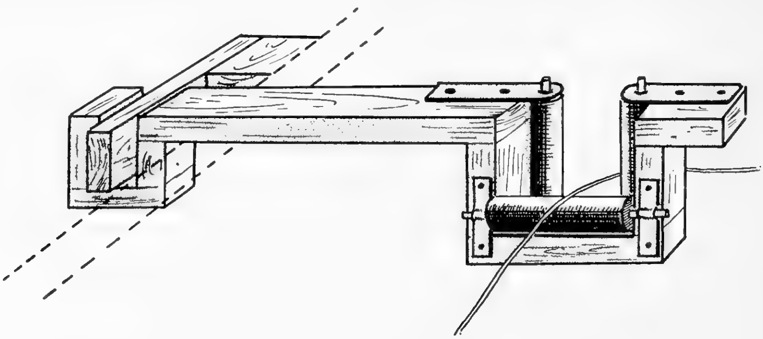
The heaviest catches of soft crabs are made during June and July. Crabs are caught throughout the season by the use of the scoop net; however, little scraping is done after the middle of July owing to calm weather. Fishermen often scrape for crabs as long as there is sufficient wind for sailing. When the wind dies down, they anchor the sailboats and use skiffs for scoop-netting in shallow water or on bottoms where the grass grows so thick that scraping is impossible. In shallow water less than 3 feet deep the crabbers often leave their skiffs and wade for the crabs.

Hard Crabs. The scrape, trotline, and dredge are used for taking hard crabs. Since crabbing with scrapes has already been considered, further discussion is unnecessary.

The trotline is the most common instrument used for the capture of hard crabs; however, it is only effective in warm weather as cold water numbs the crabs and makes it impossible for them to seize the bait. Churchill (1918) has described the use of trotlines in Chesapeake Bay as follows:

"Trotlines are usually made of ⅜-inch diameter cotton rope, and vary from ¼ to 1 mile in length. A chain anchor, weighing about 10 pounds, is attached to each end of the line. A painted buoy, showing the location and owner of the set, is also attached. Buoys are connected to the anchor by means of a fiber rope approximately 60 feet long, depending to some extent on the depth of the water in which the line is set.

"The line is baited either by means of slipknots directly in the line itself or in snoods 6 or 8 inches long attached to the line at intervals of about 18 inches. Dried



(*Courtesy U. S. Fish and Wildlife Service*)

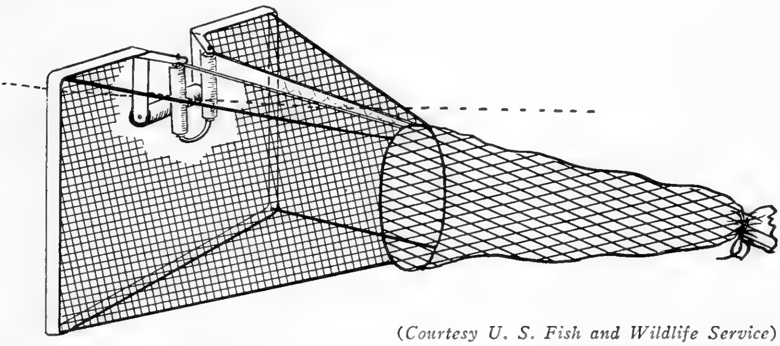
Fig. 29–4. The roller and bracket type trotline apparatus.

or salt fish or some cheap meat is used as bait. When the fishing begins, the boat moves along the line which is passed over a roller located in a bracket attached to the side of the boat. As the line is lifted to the surface by passing over the roller, the crabs are taken off the bait with a short-handled dip net and sorted as to size and condition.

"If the boat is equipped with an automatic net arrangement, the crabs are knocked off the line into a net as the bait goes across the roller in progressing along the line. It is more difficult to grade the crabs with this type of apparatus. When the net is full or the end of the line is reached, the net is swung over the deck of the boat and emptied by untying a cord at the end of the net and dumping the crabs into a barrel.

"The most successful trotline fishing is done in the early morning just at daybreak. It is believed that when the sun is shining directly on the crabs they will drop off the bait before they reach the surface of the water. Usually crabbing ceases before noon so that the day's catch can be delivered to the picking plants before it is damaged by being out of the water too long.

"When the day's fishing is completed, the line is rebaited, salted heavily to preserve the bait, and coiled in a barrel covered with a sheet of canvas or tarpaulin. It is thus ready for fishing the next morning."



(Courtesy U. S. Fish and Wildlife Service)

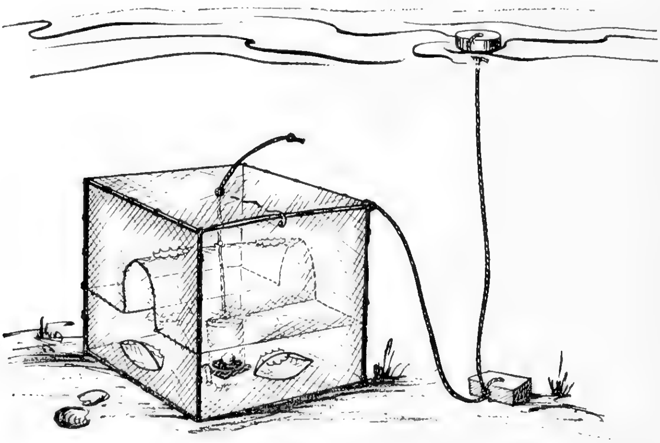
FIG. 29–5. The automatic dip-net for removing crabs from the trot line.

In winter, when most of the crabs retire to deep water and either partially bury themselves in the sand or lie inactive on the bottom, they are captured only with dredges. Fifty- to 60-foot sailboats, equipped with auxiliary engines, are used in dredging. The dredge resembles the scrape in many ways, although it is much larger and has a row of teeth about 4 inches long on the bottom. Its length varies from 5 to 7 feet, and the bag is usually only about 2 feet long. The lower part of the bag is constructed of iron mesh, the upper of cotton. A dredge is usually dragged from each side of the boat by means of a chain about an inch in diameter which passes over a roller and around a pulley attached to a stout post placed upright in the middle of the boat and thence down and around a windlass in the hold. The 2 windlasses are operated by the engine controlled from the pilot house. The dredges are hauled in alternately and their contents dumped on deck. Two men are required to handle the dredge, one working forward and the other aft of the dredge. The crabs are raked from the debris by hand or with small hooks,

culled, and shoveled into barrels. The debris is thrown overboard. The average catch of crabs by the dredge boats is about 10 barrels, but varies widely from day to day. Catches as large as 50 barrels are occasionally reported.

Formerly, few crabs were caught in Chesapeake Bay in winter; but in recent years many dredge boats have operated throughout the winter, and consequently several picking houses have remained open.

The Crab Pot. The crab pot was introduced in the Chesapeake Bay area in 1938. It consists of a box 2 feet square, constructed of wire mesh on a rigid metal



(Courtesy U. S. Fish and Wildlife Service)

FIG. 29–6. The crab trap, or pot, commonly used in the Chesapeake Bay area.

frame and divided into a lower or bait chamber, which contains a cylindrical bait cup in its center, and an upper or trap chamber. The crab, attracted by the bait, enters, swims upward after grasping at the bait, goes through the opening into the trap chamber, and is imprisoned.

General practice is to set the pot with a buoy attached in about 4 fathoms of water. In Maryland each licensee is limited to 35 pots; in Virginia, 50. Extensive restrictions by state laws have been placed upon pots to keep them from harming small crabs and other marine life and to keep them away from navigation channels. To permit the escape of undersized crabs 1½-inch mesh is prescribed.

One man can fish a series of pots from one small boat. The average yield is between 2 and 5 barrels per day, with peelers ranging around 1 per cent. The bait most frequently used is salted fish heads or menhaden. At times of bait shortage crab potters have been known to discontinue crabbing altogether.

The fragility of the pot makes it liable to destruction in storms and very susceptible to corrosion from salt water. It is necessary to have new pots each season, except in those cases where they are tarred periodically; often replacements are required during the same season. They are usually constructed by the crabber himself and the cost is small. An estimated 60,000 were operated in 1947 in Chesapeake Bay and its tributaries.

Marketing. The larger boats, such as the scrape boats and dredge boats, which are equipped with sails or power or both, usually deliver their own catch directly to the crab house. The smaller crabbers and those operating in isolated regions sell their catches to buyers who make regular trips in boats called "run boats" or "buy boats." A "run boat" has a captain who is merely the agent of a dealer and works on a commission; whereas, a "buy boat" is owned and operated by the dealer. In addition to buying crabs these boats usually sell bait. Most of the dealer's boats in Chesapeake Bay operate from either Crisfield, Md., or Hampton, Va.

Soft Crabs. The crab houses which handle soft crabs and peelers are known by the trade as "shanties," "shedding houses," and "soft-crab houses." These houses are usually small wooden buildings built on pilings over the water. The peelers are put into floats tied to stakes in the water nearby and left until moulting occurs; the resulting soft crabs are then removed and packed for market. The floats commonly used in the Crisfield region are constructed of pine or cypress and measure about 4 by 12 feet by 15 inches in depth. The sides are constructed of laths, placed vertically with ¼-inch spaces between them. The bottoms are made of 6-inch boards and are continuous. In order to support the structure evenly on the water an 8-inch wooden wing is constructed around the outside halfway from the top. In other sections of Maryland other styles of floats are used, but they differ chiefly in size and depth from those described above.

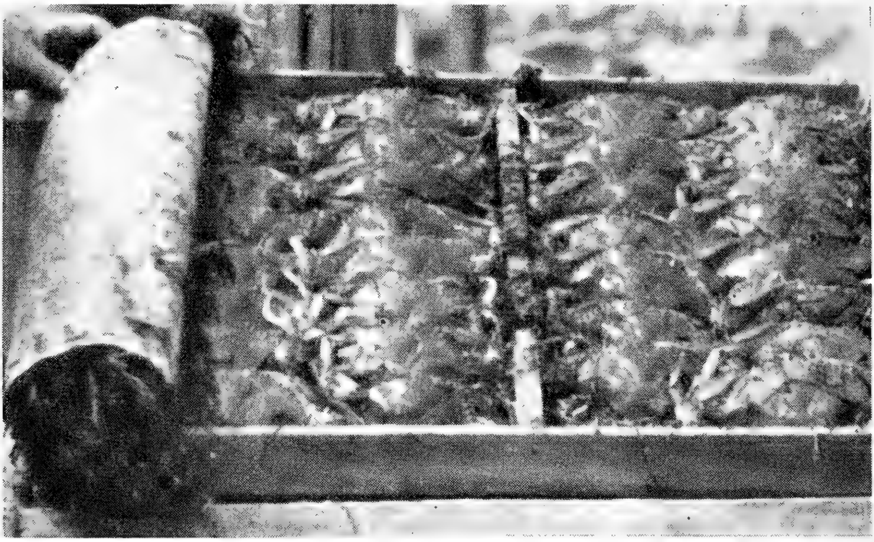
When the crabs are placed in the floats, they are sorted into various lots. "Green" peelers which will not shed for several days are placed in certain floats; crabs in the more advanced stages are put in others; and "rank" peelers or crabs actually shedding or about to do so are placed in shedding floats. A "buster" is a crab in which the back shell has cracked loose from the apron and will complete the process of shedding within an hour or so. The crabs are not fed during their confinement in the floats. Many of them die, the proportion depending upon the weather. A sudden change in the temperature of the water often kills as many as one-third.

A freshly moulted crab is very soft and dies very quickly if shipped; therefore, the crabs are allowed to remain in the floats for a few hours after shedding before being removed for packing. The soft crabs are "fished out" of the float about 3 times each day by means of a small, shallow hand net. If they are not removed for 48 hours after moulting, a tough leathery shell will have formed and the shell will have become too hard for commercial use as a soft crab. Such crabs are called "buckrams" and are sometimes sold; however, they are of little value for culinary purposes as their tissues are watery and contain little meat.

Soft crabs are always shipped alive. Before shipping they are sorted into 4 grades or sizes. The smallest of these are culls, which average about 3½ inches in width. Medium crabs vary from 4 to 4.5 inches in width; prime crabs range from 5 to 6 inches; and jumbos exceed 6 inches. The primes are the most valuable grade. These sizes are not fixed, but vary somewhat depending upon the packer, the quantity of the catch, and the state of the market. In shipping to some markets the large crabs are not graded as jumbos, but are included with the primes.

Great care is used in packing soft crabs for they must reach their destination alive. They are packed in shallow wooden trays about 3 or 4 inches in depth. Each tray is of sufficient depth to accommodate 1 layer of crabs. A layer of sea-

weed is spread over the bottom of the tray and the crabs are placed on it mouth up and in rows inclined at an angle of about 60 degrees. Crabs live longer in this position than if lying flat as the water does not run out of their gills so quickly. A sheet of parchment paper is placed over the crabs, and this is covered with seaweed and cracked ice. Two or 3 trays of crabs are placed in a crate. The most



(Courtesy U. S. Fish and Wildlife Service)

Fig. 29–7. Soft crabs are packed in trays which are in turn packed in crates for shipment to the distant markets. Each tray is covered with a layer of wet seaweed to protect the soft crabs from sudden changes of temperature.

common size crate is one which holds about 15 dozen prime crabs and weighs about 80 pounds when packed with ice. Most of the crabs reach their destination alive, except in extreme hot weather when a number die if transported long distances.

Hard Crabs. Some hard crabs are shipped alive in barrels with ice. The large whole crabs, called "Jimmies," are usually selected especially for these shipments. A few steamed crabs are shipped whole on ice, but the great bulk of the hard-crab catch is steamed, the meat picked out and shipped on ice or canned.

Preparation of Crab Meat. The first operation in the preparation of crab meat is the steaming or cooking of the crabs. One of the most up-to-date methods of cooking crabs is to place them in circular iron framework baskets, about 3 feet in diameter and 16 inches in depth. Two or 3 such baskets are hoisted by means of a hand-operated crane into a cylindrical metal tank of slightly greater diameter. A heavy iron lid is clamped on the tank or cooker, and steam is passed into it for about 25 minutes. The steaming kills the crabs and cooks the meat; the shells change from blue to bright red.

One Virginian "crab factory" places the crabs in iron framework cars about 7 feet long, 2 feet deep, and 2 feet wide, which are run on a track into rectangular horizontal cookers which hold two cars.

The cooked crabs are dumped on picking tables where the back shells are removed and the meat is picked from the body by means of a sharp pointed knife. The pickers are paid according to the amount of meat prepared. An experienced picker can remove from 60 to 70 pounds in a day.

The pickers divide the meat into 3 grades, depending upon the region of the body from which it is taken. The "lump" meat is from the muscles which operate the swimming legs or back fins, and is considered the best. The "white" or "flake" meat is made up of the remaining muscles of the body, with the exception of the claws, and ranks second in value. The "claw" meat brings the lowest price because of its dark color. Many persons, however, prefer its flavor to that of the other grades. The 3 grades are packed separately in tin cans, with perforations in the bottom. These cans, which hold from 1 to 5 pounds, are packed in barrels with ice before shipping by express.

A gallon of meat weighs about 5 pounds. The amount of meat obtained per barrel of crabs depends upon whether they are "fat" or "poor." In the spring and early summer, when the muscles are shrunken, the crabs are referred to as "poor." In late summer, fall, and early winter the muscles are full, and the crabs are called "fat." Fat crabs yield about 20 pounds, whereas poor crabs give only about 15 pounds of meat per barrel.

Some clean back shells are shipped with the cans of meat for use in the preparation of deviled crab. The shells are first "knocked out," by which process the portions of the reproductive organs and liver (which are popularly called "fat") adhering to the shells are removed. The shells are then placed in large wire crates or baskets and washed. The washed shells are dried by being spread either on a floor or wharf or in shallow trays about 10 feet long by 4 feet wide, consisting of a frame of narrow boards with a bottom of chicken-wire fencing.

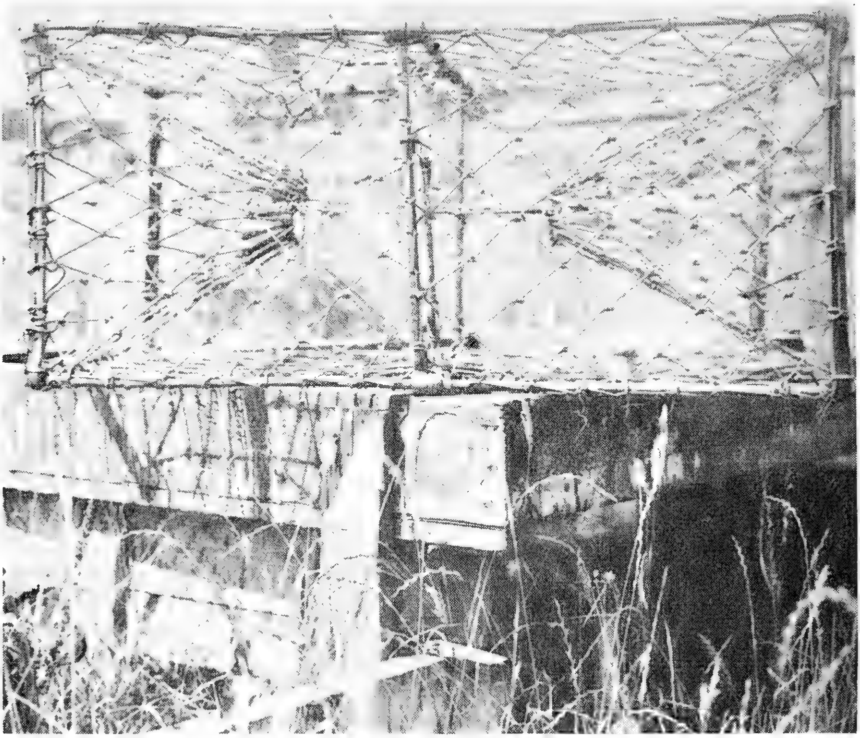
Pacific Coast Fishery

The edible crab, dungeness (*Cancer magister*), of the Pacific Coast, is found from Unalaska to Magdalena Bay, Lower California. The most important fishery is at San Francisco; other important fisheries are located at Eureka, California; on the Puget Sound, Washington; and at Wrangell and Petersburg, Alaska. In Oregon crabbing is carried on extensively at Coos Bay, Yaquina and about the mouth of the Columbia. In British Columbia this fishery is conducted at Boundary Bay, at Prince Rupert, and on a smaller scale at many other points.

The flesh of this crab undergoes changes at moulting time which make it undesirable for food unless taken in full soft shell. It is not possible with the methods in use to take moulting crabs as they are not attracted by bait. This eliminates soft crabs from the markets on the Pacific Coast.

California laws forbid the taking of crabs from August 1 to November 15, inclusive, and crabs smaller than 7 inches. The legal size is 6½ inches in Washington and 6 inches in Oregon and British Columbia. The closed season in Oregon and Washington extends from July 1 to September 13. British Columbia has no closed season. In Alaska the 1950 regulations forbid the taking of female crabs for commercial purposes. Only those male crabs measuring more than 7 inches across the greatest width can be used.

Methods of Fishing. At Eureka and San Francisco, California, where fishing is done chiefly in exposed waters off the harbors, hoop nets are exclusively used.



(Courtesy U. S. Fish and Wildlife Service)

Fig. 29–8. One type of trap used for dungeness crabs.

These nets consist of 2 iron hoops connected by netting to form a basin-shaped receptacle, which lies flat on the bottom when fishing and from which the crab cannot crawl. Fifteen to 25 of these are baited and set on a long rope in line with the run of the tide. About every hour the nets are hauled up and the catch removed. The hoop nets are usually taken ashore at night.

A pot or trap similar to the Maine lobster pot is used in sheltered bays and sounds. Gray (1922) has described the traps used and the method of fishing in Alaska. The traps are made of a framework of iron rods, covered on the sides with wire netting; the ends are made in the form of funnels of linen or cotton web, through which the crabs may enter. They are about 40 inches long, 30 inches wide, and 20 inches deep, and are baited with salmon waste. In the summer they are set in the water to a depth of 2 to 8 fathoms, in the winter as deep as 25 fathoms. The traps are lifted once or twice daily; crabs, measuring 7 inches or more, are removed, and the females and undersized are released. Those retained are kept in a live box until delivery at the cannery. Dungeness crabs will live out of water about 12 hours; but, if they are kept in sea water, they will live much longer, particularly if the weather is cool. Crabs of all species are extremely cannibalistic and will eat each other when hungry; therefore, when retained for any considerable period of time they should be fed on dead fish or other animal matter.

Owing to the limited demand for live crabs in Alaska the bulk of the catch is canned and shipped to the United States.

Most of the crabs caught in California are sold in San Francisco. Portland, Seattle, and Tacoma are other important crab markets on the Pacific Coast.

Methods of Capturing Alaska King Crabs

Tangle Nets. These nets are made of 18-thread medium laid cotton netting attached to a ¼-inch diameter float and lead lines. The mesh is of 18-inch flat stretch measure. The net is 10½ feet deep, 150 feet long on the lead line, and 165 feet on the float line. Glass buoys and lead sinkers are used, and the net is anchored at each end so that it hangs loosely near the bottom. The nets are usually set and fished from small open boats, and as many as 20 may be attached and fished together. They are arranged parallel to the shore line or with the prevailing wind and current.

The crabs become entangled in the mesh and are brought to the surface when the net is lifted at intervals during the fishing period. They are removed by hand, which is costly as it is time consuming, and stored on deck until they are butchered for cooking; the net is then reset for more fishing.

Trawl Fishing. The otter trawl used in fishing for the king crab varies only slightly from that used for years in taking bottom fish from the North Atlantic. The vessels operating in the Bering Sea area are equipped to handle fish as well as crabs. This type of gear is more efficient as it skims the bottom and captures all species of sea animal. When the trawl has been lifted and dumped on deck, the various species are separated and sorted; those suitable for commercial use are saved, and the others are thrown overboard.

Canning Crab Meat

In 1945 6,475 cases of rock crab, valued at $214,000, were canned in Maine and Massachusetts. In 1948 no production of canned rock crabs is indicated for these states. The complete statistics for canned crab meat, according to states and areas, are shown in Tables 134 and 135.

Blue Crab. Canning blue crab has never developed into a sizable industry because of the ready market for crabs in the fresh or boiled condition. The points of production are geographically located near the points of consumption, and a fresh supply is readily available.

Canning blue-crab meat by the usual processing methods has resulted in a product of inferior flavor and color. Fellers (1936) patented a process for eliminating this difficulty to a considerable extent. He has suggested that the changes are largely the result of a breakdown of the unstable proteins due to the influence of heating. This releases both sulfur and ammonia compounds in the meat during the canning process. The blood of the crab contains a copper compound known as hemocyanin, which reacts with the liberated ammonia and sulfur compounds. The oxidation of these compounds results in the characteristic blue color in the meat.

The Fellers patent is based on treating the crab meat by dipping it in a brine solution containing lactic acid. The strength of the lactic acid is just sufficient to insure an acid pH of the meat. Small amounts of aluminum or zinc sulfate are contained in the above brine dip, not in excess of 0.04 per cent.

The crabs to be canned by this process are selected according to season, sex,

TABLE 134. UNITED STATES PACK OF CANNED CRABS, 1948.

The 1948 pack of canned crabs amounted to 220,802 standard cases, valued at $4,846,494 to the canner. This was an increase of 58 per cent in volume and 79 per cent in value compared with the previous year. The 1948 pack was the largest in history, exceeding the previous record, established in 1946, by nearly 22,000 cases. The increase in production occurred on the Pacific Coast, where the pack totaled 187,420 cases, a gain of over 81,000 cases compared with the previous year. Three species of crabs were canned in 1948: Pacific Coast dungeness crabs, 169,798 cases; Atlantic Coast blue crabs, 33,382 cases; and Alaska king crabs, 17,622 cases.

State and species	Standard cases	Value	Can size and number of cans to case	Actual cases	Value
Maryland, North and South Carolina, Georgia, Alabama, and Mississippi (blue)	18,862	$361,200	6½ ounces (48 cans)	188,429	$4,243,071
Louisiana (blue)	14,520	220,672	6½ ounces (24 cans)	[1] 61,234	[1] 556,072
Washington (dungeness)	104,362	2,295,905			
Oregon and California (dungeness)	56,982	1,338,349	13 ounces (24 cans)	1,079	25,896
Alaska:					
Dungeness	8,454	186,368	3¼ ounces (48 cans)	1,355	21,455
King	17,622	444,000			
Total	220,802	4,846,494	Total	252,097	4,846,494

[1] Includes a small pack of 5-ounce cans, packed 24 to the case.

Note: "Standard cases" represent the various-sized cases converted to the equivalent of 48 cans to the case, each can containing 6½ ounces of crab meat. Crabs were canned in 6 plants in Louisiana, 21 in Washington, 9 in Oregon, 10 in Alaska, and 1 plant each in Maryland, North Carolina, South Carolina, Georgia, Alabama, Mississippi, and California.

Source: U. S. Fish and Wildlife Service.

TABLE 135. PACK OF CANNED CRABS, 1939 TO 1948.

Year	Atlantic Coast and Gulf States		Pacific Coast States and Alaska		Total	
	Standard cases	Value	Standard cases	Value	Standard cases	Value
1939	9,728	$75,502	23,100	$184,254	32,828	$259,756
1940	13,486	130,869	25,254	178,021	38,740	308,890
1941	22,494	235,745	37,704	311,872	60,198	547,617
1942	29,656	397,772	84,892	1,357,293	114,548	1,755,065
1943	26,716	412,310	48,592	782,173	75,308	1,194,483
1944	36,386	560,735	50,556	800,723	86,942	1,361,458
1945	29,788	484,869	25,726	398,898	55,514	883,767
1946	120,150	2,536,405	78,928	2,183,714	199,078	4,720,119
1947	33,696	667,487	106,120	2,037,904	139,816	2,705,391
1948	33,382	581,872	187,420	4,264,622	220,802	4,846,494

Source: U. S. Fish and Wildlife Service.

locality, and time of moulting. Lightly cooked crab meat is packed in parchment-lined, 6.5-ounce flat cans, sealed under high vacuum and processed at 250° F for 30 minutes. It is recommended that the flake or lump meat be canned separately from that removed from the claws. The analysis of canned blue crab meat is shown in Table 136 (Fellers, 1940).

TABLE 136. ANALYSIS OF CANNED BLUE CRAB MEAT.

Composition	%	Mineral content	P.P.M.
Moisture	79.00	K	1880
Dry matter	21.00	Ca	1330
Protein ($N \times 6.25$)	18.00	Mg	120
Total ash	2.20	P	380
Ether extract (fat)	0.40	Fe	20
Ext. matter (by difference)	0.40	Cu	13
Cal./100 g 77.00		I	0.46
Alkalinity of ash 11.7			

Vitamin content per 100 g.

Ascorbic acid	0.012 mg (24 IU)
Thiamin	230 gamma (70 IU)
Riboflavin	150 gamma (60 Bourquim-Sherman units)

Dungeness Crab. The dungeness crab is canned in Oregon, Washington, and Alaska. It is a much larger species than the blue crab of the Atlantic and Gulf coasts, and some specimens measure 9 inches across the back of the shell. In Alaska it is illegal to take any of these crabs measuring less than 7 inches across the widest part of the shell; in Oregon and Washington the size limit is 7½ inches. Alaska establishes a closed season when no crabs are taken legally. While there is no closed season in Oregon and Washington, the greatest canning activity is during the summer months, when production is high and prices are low.

The greater portion of dungeness crabs are taken in pots, a boxlike trap similar to that described for the blue crab of the Atlantic and Gulf coasts. The pots are set 150 to 300 feet apart in 6 to 15 fathoms of water. The traps are set and hauled by small powerboats equipped with a boom and power gurdy. When fishing the traps the boat picks up the trap by means of the buoy line, hauls it on board, and sets a new baited trap. While the boat moves on to another trap, the first is unloaded and rebaited so that it can replace the next one pulled. It is estimated that 2 skilled men can handle about 150 traps a day and, if fishing is good, catch about 150 crabs. The crabs are placed in a live box and held until a "pick-up" boat from the cannery arrives; in some cases the fishermen deliver them to the cannery. These crabs will not live long during extremely warm days or when exposed to the sun.

Jarvis (1943) describes the method of handling dungeness crabs in the cannery as follows:

"The crabs are taken to cleaning tables where a workman removes the back shell or carapace by hooking the edge of the shell over a stationary hook and giving a sharp jerk. Another workman then cuts each crab in half by bringing the body down across a large knife blade fixed to the table. The viscera are removed and the body is thoroughly washed in a jet of fresh clean water under considerable pressure. This water is warmed sufficiently so that the hands will not be numbed in washing the crabs.

"The cleaned and washed portions are taken to large cooking tanks filled with fresh water heated by live steam. In some canneries sodium bicarbonate is added in the proportion of ½ pound to 40 gallons of water. This practice is not recommended and should be abandoned. It serves no useful purpose, increasing the natural alkalinity of the crab

meat and neutralizing the effect of the acid dip given later in the packing operation. The crabs are dumped into the tanks of boiling water and cooked for an average period of 20 minutes.

"Some packers precook the crabs in a steam chest for about the same length of time at a temperature from 212 to 220° F (100 to 104.4° C). More of the flavor of the meat

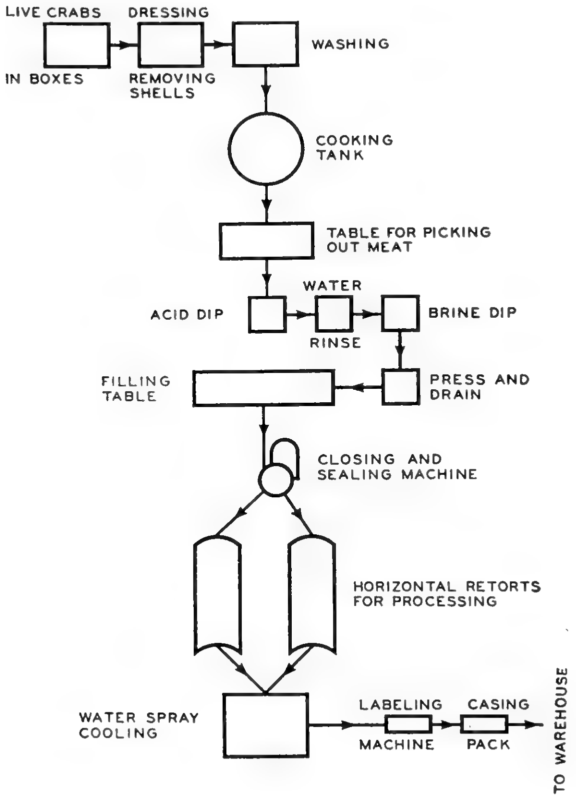


Fig. 29–9. Flow sheet for the procedure in canning dungeness crabs.

(Courtesy U. S. Fish and Wildlife Service)

is believed to be retained by this process, but packers who use the boiling-water cook claim the meat is more readily picked from the shells.

"The crabs are given to the pickers immediately after cooking as the meat is removed more rapidly and completely if picked before the crabs have cooled. In picking the workers break the shell on the legs with a small wooden mallet, then pound the shell of the body against the pan in which the meat is to be picked; this loosens and releases the meat without breaking it into small flakes. Body meat and leg meat are kept separate, and about equal proportions of each are obtained. Unlike the crab meat of the Atlantic Coast the leg meat is considered as the higher grade.

"The picked meat is dipped in a dilute acetic acid solution for about 1 minute. This solution is made up in the proportion of 2 ounces of 28-per cent acetic acid to 1 gallon of water. Following this treatment it is washed in fresh water and dipped in a 100° salinometer brine. The meat is then pressed to remove excess moisture, drained, and taken to the filling tables.

"Dungeness crab is packed in cans of 3 sizes: "half flats," "pound flats," and "No. 2" cans, with net weights of 6½, 13, and 17 ounces respectively. All cans are lined with

"C" enamel, seafood formula, and a lining of vegetable parchment paper is inserted as an added protection before filling. Hand packers fill the bottom, top, and sides of the cans with a layer of leg meat, while the center is filled with body meat. About ¼ ounce of salt is added to each can.

"The trays of filled cans are sealed in a vacuum-closing machine. The sealed cans are packed in salmon coolers and processed. There is some variation in processing, but all packers agree that it must be closely controlled and that 10-pound steam pressures have an adverse effect on the color of the crab meat. Representative processes now in use are: half flats, 90 minutes at 221° F (105° C) (3-pound pressure); and 1-pound flats and No. 2 cans, 80 minutes at 228° F (108.9° C) (5-pound pressure). The cans, upon removal from the retort, are cooled by a water-spray system. When the cans are thoroughly cooled and cleaned, they are labeled and packed in wooden or fiber-board cases, holding 96 half flats, 48 1-pound flats, or 24 No. 2 cans."

Rock Crab. Canning rock crab has never developed into an industry of economic importance. A considerable quantity was packed during World War II when food of every kind was needed. Since then reports of production indicate that only a few hundred cases have been packed each year.

Alaska King Crab. Japanese crab-canning operations, in which complete canneries were installed on 2,000- to 3,000-ton vessels ranging Alaskan waters, were

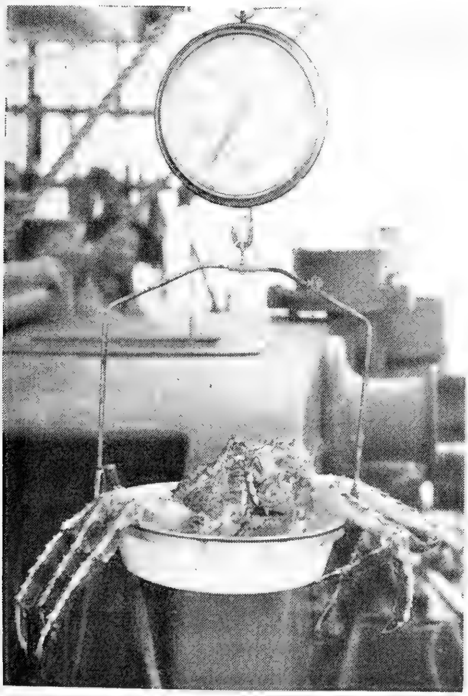


FIG. 29–10. A slightly larger than average king crab.

(Courtesy U. S. Fish and Wildlife Service)

begun in 1932. Each year until the end of the 1940 season in July from 1 to 4 of these floating canneries operated in this area.

The United States fishery for king crab during this period was of minor importance; king crabs were only caught incidentally when other species were fished.

In 1941 the United States Government sponsored an investigation to obtain information as to the potential value of this industry. The experimental factory vessel was fitted to conduct biological research into crab populations and locations, technological research into methods of canning, and fishing gear research to determine the most efficient methods for catching the crabs. Both tangle nets, similar to those used by the Japanese, and the Atlantic Coast-type otter trawls were used in the investigation.

In 1946 several commercial vessels were fitted to operate in the king-crab fishery in Alaskan waters. One of these vessels, the "Deep Sea," was fitted to can the crab meat at sea and, also, to freeze it for the fresh market; others were designed for freezing only. After one trip the canning line of the "Deep Sea" was discontinued because of mechanical difficulties in operating in rough weather. These vessels have continued to produce frozen king-crab meat.

The factory ship, "Pacific Explorer," under lease to a commercial fishing firm in 1948, operated in the Bering Sea area. This vessel has 8,500-tons displacement and is equipped with a canning line, freezer, and by-products plant. It operated in conjunction with 4 smaller fishing vessels, processing their catch. At the end of the operating period of 4 months 18,235 cases of 48½-pound flat cans were packed.

Trawl Fishing. The otter trawl used in fishing for king crab varies only slightly from that used for years in the North Atlantic for taking bottom fish. The vessels operating in the Bering Sea area are equipped to handle fish as well as crabs. This type gear is more efficient as it skims the bottom and captures all species of sea animal. When the trawl has been lifted and dumped on the deck the various species are separated and sorted, those suitable for commercial use are saved, the others are thrown overboard. A description of the otter trawl and its operation can be found in Chapter 13.

Canning Procedure. *Butchering the Crabs.* If the crabs are kept moist with ocean water and protected from the sun until they are butchered, they will remain alive and not be subject to enzymatic and bacterial breakdown, which affects the quality and flavor of the canned product.

The first operation in butchering is the removal of the back shell or carapace. This is done by hooking the shell over the sharp edge of the butchering tool. The lower or ventral shell is then broken in two along the mid line, leaving the legs attached to each portion. The gills, viscera, and all refuse are then removed by washing and trimming.

Cooking. The cleaned carcasses are immediately placed in a vat of boiling water, where they remain for 15 or 17 minutes. The time is calculated as soon as the water resumes boiling after the addition of the carcasses. The Japanese boil the carcasses in sea water and obtain a product of very high quality. The American industry has equally good results with both fresh water and with 3-per cent brine solutions. After the cooked carcasses are removed from the cooking vat, they are cooled in cold running water for about 30 seconds before further handling.

Separating the Shell and Meat. The meat separates from the shell during the cooking. The legs are cut into segments the height of the can and the meat is shaken out of the shell into a pan, leaving the tendons attached to the shell. The leg and body meat are kept separate until packed in the cans. Only stainless steel or enamel-covered steel pans are used for containers as contact with any other metals causes later discoloration in the meat. When the pans are filled,

the meat is dumped into a wire basket made of stainless steel and washed with a cold water spray to remove any particles of shell.

Acid Dip and Brining. The washed meat is weighed and then dipped into a weak acid solution for 15 seconds. Acetic acid is generally used in preparing the acid dip although some packers prefer citric acid. The acid dip is prepared by adding 2 ounces of glacial acetic acid to each gallon of fresh water, a solution of pH 3.0. If citric acid is used, it is in about the same proportion and pH. There is some variation in the strength of the acid solutions used by different packers. The strength of the acid dip is maintained by the addition of fresh acid after each 100 pounds of crab meat are treated.

When the crab meat is removed from the acid bath, it is drained for a few minutes to eliminate the excess acid solution. The leg and claw meat are immersed in a 90° salinometer brine bath for about 15 seconds. The strength of the brine is maintained as nearly as possible throughout its use. The meat is again drained of adhering solution, after which it is ready to pack into cans. The "white" or body meat is seldom given the brine dip as the leg meat absorbs sufficient salt to flavor the canned product.

Packing and Processing. Crab meat is generally packed in parchment-lined, C-enamel sea food formula, ½-pound flat tin cans; occasionally a packer will use ¼- and 1-pound cans for special markets. Large pieces of leg and claw meat are placed in the top and bottom layers; the body meat and broken pieces of the leg and claw are placed in the center. This system of packing gives the can a nice appearance when it is opened. The tops are vacuum-sealed on the cans. They are placed in a retort where processing takes place for 75 minutes at a pressure of 230° F (110° C) (6-pounds pressure). This pressure and temperature are very critical and are generally automatically controlled since overcooking adversely affects the color, flavor, odor, and texture. The cans are cooled in a spray of cold water as soon as they are removed from the retort. The final operation is labeling and packing into cases which will hold 48 cans.

Freezing Crab Meat

According to the reports of frozen fishery products for 1949 there were 814,567 pounds of crab products (i.e., both soft crabs and crab meat) in frozen storage December 1, 1949. The holdings on the Atlantic, Gulf, and Pacific coasts are included as well as the 3 most popular species of crab, blue, dungeness, and Alaska king.

The Alaska king crab is usually frozen on board the fishing vessel. It is first cooked, and the legs are packed in 5- and 10-pound waxed-paper cartons and frozen. These packages are then wrapped with some type of transparent moistureproof material and marketed. The body meat from these crabs is packed in ½- or 1-pound tin containers fitted with a telescope top; these are then frozen on board the vessels.

Dungeness crab meat is cooked, packed in both waxed cartons and telescope-top cans of the above capacity, and frozen for market. Some packs of this crab meat are placed in hermetically sealed tin containers for freezing and storage.

Blue crabs are more often frozen when in the soft state. Each individual soft crab is placed in a cellophane bag or some similar container, sealed by heating the opening with a special heating iron. These individual containers are then packed

in waxed cartons containing units of a dozen, that is, ½ dozen or 1 dozen or more crabs to the container, and marketed this way. Some packers eviscerate the soft crabs before freezing. The comparative efficiency of these techniques has not been sufficiently studied.

The meat from the hard variety of this species is first cooked and removed from the shell, then packed in ½- and 1-pound containers. The cooked crab meat does not retain its quality for more than 2 or 3 months in frozen storage, and, therefore, it is moved into sales channels as rapidly as possible.

Some crab cakes and deviled crabs are frozen; these are usually prepared according to the standard recipe for these products. They are precooked, placed in individual approved types of containers, and frozen in units of a dozen; these are ready to serve when defrosted and reheated. This is a comparatively new development in the industry and is still in an experimental stage. It remains to be determined whether or not the seasoning in the recipe changes in flavor over long periods of storage as has been the experience in the case of many of the precooked frozen foods. In the short time that these have been available they have become very popular.

By-products

The waste material, consisting of viscera and shell, from the crab meat picking plants is sold to reduction plants. The reduction plants usually process the crab waste separately from other material since the dried ground shell material is considered a valuable addition to mixed diets for baby chicks and laying hens.

Analysis of Dried Blue Crab Scrap	%
Moisture	6.04
Calcium carbonate	44.06
Calcium phosphate	8.54
Protein ($N \times 6.25$)	28.13
Sulfates	0.30
Undetermined	12.93
	100.00

Total iodine is 560 parts per billion.

REFERENCES

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest*, **18** (1949).

Andrews, E., "Crab Pot Construction," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **262** (1948).

Andrews, E., "The 'Bob' Method of Picking Blue Crabs," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **276** (1948).

Andrews, E., "Trotline Construction, Operation, and Maintenance," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **291** (1948).

Anon., "Canned Crab Industry of Japan," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **314** (1948).

Anon., "The Alaska King Crab," U. S. Fish and Wildlife Service, *Fishery Market News Supplement* (1942).

Anon., "The Blue Crab (*Callinectes sapidus*) Fishery," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **282** (1948).

Anon., "Laws and Regulations for the Protection of the Commercial Fisheries of Alaska," U. S. Fish and Wildlife Service, *Regulatory Announcement,* **28** (1950).

Carson, R. L., "Food from the Sea: Fish and Shellfish of New England," U. S. Fish and Wildlife Service, *Conservation Bulletin,* 33 (1943).

Churchill, E. P., Jr., "Life History of the Blue Crab," U. S. Bureau of Fisheries, *Bull.,* **36,** 91–128 (1917–18).

Evans, P. W., "The Chesapeake Bay Soft Crab Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **184** (1946).

Fellers, C. R., and Harris, S. C., "Canned Atlantic Crab Meat," *Ind. Eng. Chem.,* **32,** 592 (1940).

Fellers, C. R., and Parks, C. T., "Biochemical Study Approximate Composition of Pacific Coast Crabs," *Univ. of Wash. Publ. in Fisheries,* **9,** No. 7, 139 (1926).

Jarvis, N. D., "Principles and Methods in the Canning of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.,* **7** (1943).

King, J. E., "Experimental Fishing Trip to Bering Sea," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **330** (1949).

Pottinger, S. R., "Keeping Quality of East Coast Crab Meat in Fibreboard Containers and in Tin Cans," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **185** (1946).

Watson, V. K., and Fellers, C. R., "Nutritive Value of the Blue Crab (*Callinectes sapidus*) and Sand Crab (*Platyonichus ocellatus* Latreille)," *American Fisheries Soc. Trans.,* **65,** 342–349 (1935).

Wharton, J., "The Chesapeake Bay Crab Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **191** (1947).

CHAPTER 30

The Lobster Fishery

Introduction

It has been stated that in the early colonial days lobsters could be purchased for "one penny each," indicating that the size or weight of the animal was not a consideration in the transaction. The present price for this sea delicacy is approximately 25 cents per pound to the fisherman, and much more than this when purchased on the retail market.

The lobster (*Homarus americanus*) is peculiar to the rugged coasts of New England and Canada. Many unsuccessful attempts have been made to transplant it to the waters of the North Pacific. The crustacea are found in a relatively narrow range, extending from the tide lines to a distance of 30 to 50 miles out and from Labrador to the coast of North Carolina. Occasionally, one is found on Georges Bank, a distance of more than 200 miles off the coast. It is probable that the population of lobsters is densest from Cape Cod north, but some of the largest specimens have been captured off the coast of North Carolina during winter trawling operations for other species. This has led to the development of a lobster fishery in the winter months off the Middle Atlantic states.

Early History of the Industry

As the early Puritan settlers on the New England Coast were familiar with the European lobster, they soon recognized the value of American lobster fisheries. In colonial times practically all of the lobster catch was consumed locally as there were no large inland cities and as, moreover, the fishermen had no means of rapidly transporting their catch to distant markets. Practical methods of canning were not known at that time. As a result of these conditions the lobster fishery of New England was limited to a few sections of the coast until about 1840, when transportation facilities were greatly improved and commercial methods of canning were discovered. The lobster fisheries of the United States reached their greatest extent, considered from the standpoint of quantity taken, about 1892, when 23,724,525 pounds, valued at about $1,062,392 were sold.

Location of Present Industry

Cape Cod was one of the most important centers of the early lobster industry, but since about 1870 this region has been succeeded by Maine. Massachusetts ranks second; New Hampshire, third; Connecticut, fourth; and Rhode Island, fifth.

Canada is the most important lobster-producing country, its product exceeding that of all the rest of the world combined. The Canadian lobster fishery is largely centered in Nova Scotia. All lobsters caught in the United States are consumed

fresh, and none is canned; but in Canada the value of the canned lobsters packed exceeds that of the lobsters consumed fresh. The greater proportion of Canadian lobsters, both canned and fresh, are exported to the United States. Newfoundland is also an important center of the lobster industry.

The European lobster industry is located chiefly in Norway, Ireland, Scotland, England, Sweden, and France. However, during recent years it has declined so rapidly that it is now of minor importance.

Decline of the Fishery

In the early days of the American lobster fishery these crustaceans were very plentiful and consequently very cheap. They were much in evidence along the shore after storms, during which many were killed and washed upon the beaches. When plentiful they were commonly taken by gaffing from small boats, but such methods were discarded long ago because of the growing scarcity of the catch. As the number of lobsters taken has declined, the price has rapidly advanced. Prior to 1860 large lobsters were often retailed at 5 cents each; similar lobsters now bring from 50 to 75 cents. In 1888 the average annual catch per pot in Massachusetts during the season was 81 lobsters, each one over 10.5 inches in length. By 1905 the average annual catch per pot had declined to 31 lobsters, each one above the 10.5 inch gauge. No comparative figures are available for more recent years, but the decline has continued. In spite of state regulation of the size which may be taken it is evident that the American lobster is in grave danger of extermination.

Since the Canadian and Newfoundland lobster fisheries have been developed more recently than those of the United States, these fisheries have not as yet been depleted to a similar extent. However, the annual catch is undergoing a rapid decline. At the height of the Canadian industry the annual catch was approximately 200,000,000 lobsters, but in 1920 it was only about 40,000,000. In 1946 the total production of lobsters was 38,308,500 pounds, valued at $11,365,037.

Conditions have been much the same in Europe. When intensive fishing was commenced, the lobsters were rapidly depleted. The Norwegian lobster fishery reached its height in 1865, when 1,956,276 lobsters were caught. Recently the high price has greatly augmented the numbers of Norwegian fishermen; because of this the size of the catch has not yet decreased to any considerable extent, but it is doubtful that the natural increase of lobster will be sufficient to permit more extensive fishing for an extended period.

Life History of the Lobster

Larval Stages. Because of the commercial importance of the American lobster (*Homarus americanus*) and the rapid decline of this fishery many researches relative to its physiology and propagation have been carried out. The life history of the lobster is unique in many respects and is one of the most interesting studies in marine biology.

The great majority of lobsters reach sexual maturity when about 10 inches long, but a few spawn when 7 inches long. The number of eggs in the first litter varies from about 3,000 to 9,000. Most authorities agree that the American lobster spawns once every 2 years and that the lobsters continue to grow until they are 20 or more inches long; the greatest recorded length is 23.75 inches and the

greatest weight, 34 pounds. The largest specimens captured invariably proved to be males. The number of eggs laid increases rapidly with the size of the crustacean. The eggs are usually laid during July or August, or sometime later in the year. All of them are extruded at one time, and are not discharged into the sea

(Courtesy Wayne Buxton, Maine Development Commission)

FIG. 30–1. A female lobster carries 10,000 to 100,000 extruded eggs attached to her swimmerets for one year before they are hatched.

water to float about until they hatch as is the case with fish spawn; instead, they become attached to the swimmerets on the underside of the mother's tail by a glue or cement of unknown composition, which is excreted simultaneously with the spawning. The eggs remain attached to the swimmerets and gradually develop for 10 to 11 months, at the end of which period the eggs hatch gradually. Hatching usually takes a little over a week.

The newly hatched larval lobster possesses a short shrimplike body and ringed tail stretched out almost horizontally. The larva is of glassy transparency, with gleaming emerald eyes, and possesses a huge pointed snout or rostrum. Two pairs of very short horns, the second pair being forked, protrude in front (*antennae*

and *antennulae*). Four of the 6 tail joints bear spines, 2 on each side, and 1 standing erect in the middle. The yellow liver is plainly visible through the translucent shell. The third pair of foot-jaws and 5 pairs of legs bear paddle-like outer branches, by the rapid movement of which the larval lobster swims about at a moderate speed. During this stage the head is commonly directed downward and the body usually bent in quadrant form. The direction is aimless unless influenced by light and food and the like. At this stage the larva is about ⅓ of an inch in length from the tip of the snout to the end of the tail.

During the first 2 weeks of its existence the larval lobster moults 3 times, changing slightly in appearance after each moult. The life of this crustacean is made up of a series of stages, each of which represents the time passed between successive castings of the shell. During the first 4 periods the growth is most rapid and changes most pronounced. After the sixth or seventh moult there is little apparent change, except for increase in size. Herrick (1909) described the changes in the larval state of the lobster in great detail; a brief outline of his description follows:

Toward the end of the second week the green color begins to be observed along the back of the young lobster. The paired swimmerets can be seen along the underside of the tail, and the snout becomes toothed. At this stage the larva is approximately ½ inch long.

The large claws begin to develop during the third week, with the toothlike projections along the inside becoming visible. The eye does not show any appreciable change at this time, but the green coloration can be observed as spots in the thin shell.

The resemblance to the adult lobster becomes more noticeable during the fourth week. The color is appreciably more pronounced and the length has increased to something more than ½ inch. The color has deepened to a reddish brown and the erect spines down the back have disappeared.

It is during the period from 6 weeks to 2 months that the young lobster completely loses the translucency which has been characteristic of it so far. It is still an active surface swimmer, but its new reddish brown tint makes it harder to distinguish from the larva of many other species, such as the young cod or sculpin, which live in the surface water.

After 1 or 2 weeks more, when it is about ⅝ of an inch long, it migrates toward the shore. The color has become definitely darker and may range from dark green to pale blue or greenish brown. Its actions indicate that it will soon seek the bottom mud, where it will remain throughout the remainder of its life if left undisturbed.

When it is about 3 months old, the external characters of sex begin to develop, and it is possible to differentiate between the male and the female. It has now passed from an almost transparent mite swimming in the open sea to a heavy opaque bottom-living scavenger. The eyes have become quite prominent. It feeds on minute marine plants, other crustaceans, and in fact anything that comes within reach and is not too large for it to handle. During the first year of its life it will molt from 14 to 17 times and will gain as much as 20 per cent in bulk at each molt. It is estimated that a lobster measuring 10½ inches in length has molted about 25 or 26 times, and its age is about 5 years. A female this size will produce about 10,000 eggs each time she spawns.

Habits of the Adult Lobster. The sea bottom is the natural abode of the adult lobster, the source of its food, and the scene of all its activities. It never forsakes the water or leaves the bottom of its own accord. Lobsters wander close to the shore and out to depths of over 100 fathoms in search of prey. In traveling over the bottom the lobster walks nimbly upon the tips of its slender legs; but when transferred from sea to land it can only crawl in vain attempts to walk, owing to the greater weight of its body which its slender legs are unable to sustain. In the water the lobster is agile, wary, pugnacious, capable of defending itself against its enemies, and sometimes moves at a high rate of speed.

Lobsters do not migrate up and down the coast at definite periods or in considerable numbers as do many fishes and birds; but in the spring they come in closer to the shore and in the fall they retire to deeper water. The optimum temperature of the lobster lies between 50 and 60° F.

The lobster is essentially a creature of nocturnal activity. Adult lobsters dig up the sea bottom in their search for shellfish, and often cover themselves with mud during cold weather.

Lobsters are great scavengers and live chiefly on fish, alive or dead, and on the invertebrates which inhabit the bottom and come within their reach. They catch many small live fish and a few of the more sluggish larger fish. Adult as well as larval lobsters are cannibalistic and when crowded together quickly destroy each other.

Color. Normal adult lobsters are dark green. The hard shell is an opaque lifeless substance; its characteristic coloring is caused by pigments which are excreted by the chromatoblasts of the soft underlying skin. These are immediately exposed upon removing the shell, and the delicate skin underneath is seen to be flecked or mottled with scarlet. The excreted pigments undergo physical and chemical changes in the hard cuticular shell and may thus become a decidedly different color from the parent chromatoblasts. Upon dehydration, oxidation, and other chemical changes the pigments of the lobster shell, due to the presence of chromogens, become converted into a red lipochrome, resembling rhodophan. This accounts for the wonderful change of color which the lobster undergoes when boiled.

Propagation of Lobsters

Need of Artificial Propagation. Since lobsters are normally unable to multiply fast enough to keep up with the extensive fishing now carried out along the Atlantic Coast, it is evident that either protection or artificial propagation is required to maintain their numbers at the present level. Both means of increasing the lobster fisheries have been tried, but for various reasons neither has been very successful. Many protective laws have been enacted in states possessing important lobster fisheries and in various European countries. Table 136 (p. 637) contains a brief digest of these regulations.

Methods. Artificial propagation of lobsters was first successfully carried out by Guillon and Coste (1865). Since that time many attempts have been made to rear lobsters from eggs, but none were successful on a large scale until 1905. In that year Bumpus and Mead carried out experiments on the culture of lobsters in agitated sea water. By this method nearly half of all lobsters hatched can be successfully carried to the fourth stage, or the state at which the young lobsters

Table 136. State Lobster Regulations.[1]

	Maine	New Hampshire	Massa-chusetts	Rhode Island	Connect-icut	New York	New Jersey, Delaware, Maryland
Length of season specified	No regulation	No regulation	No regulation	Apr. 1–Dec. 30	No regulation	No regulation	No regulation
Annual report to state required on number, weight, and value of lobsters caught and number of pots fished.	Yes	Yes	Yes	Yes	Yes	No	No
Require that buoys and/or pots be marked with name and/or license number.	Yes	Yes	Yes	Yes	No	Yes	No
Legal size limit carapace measurement (Subject to changes).	3-1/8 in.	3-1/8 in.	3-1/8 in.	3-1/16 in.	3-1/16 in.	3-1/8 in.	N. J.—3-1/16 in. Del.—3-1/8 in. Md.—3 1/16 in.
Spawning or "berried" female lobsters illegal.	Yes	Yes	Yes	Yes	Yes	Yes	No regulation
License fee required.	$1.00	$5.00	$5.00	$5.00	$5.00	$15.00 incl. boat license	No
Residence requirement to obtain license.	10 yrs.	5 yrs.	1 yr.	1 yr.	Must maintain a domicile	6 mos.	No

[1] These regulations in effect spring of 1944; for latest regulations write to your state fishery authority.

Source: U. S. Fish and Wildlife Service.

begin to seek the bottom and are better able to take care of themselves. Mead (1909) found that to insure success the hatcheries must be located far enough offshore to guarantee an undiminished supply of fresh sea water; he therefore located the Rhode Island Commission of Inland Fisheries' experimental hatchery on pontoons anchored a short distance from the shore at Wickford, R. I. This hatchery is at present in operation.

The method consisted essentially of confining the larval lobsters in cars, either constructed of porous material or provided with screened openings, set into the ocean itself, and of maintaining within the cars, by mechanical means, a continuous gentle current having a rotary and upward trend.

The lobsters are hatched by placing the old female lobsters carrying eggs about ready to hatch in boxes in wells on the pontoons; the horizontally revolving paddles contained in the wells are set in motion. As the eggs hatch one by one, the larvae are carried upward and off the bottom by the current just as if they were in the ocean. The lobsters which hatch each day are placed in a separate rearing compartment, likewise equipped with a horizontally revolving paddle. This is an important feature of the method as the young lobsters are cannibalistic; if those hatched on several different days are placed in the same car, the older individuals devour the younger ones when they moult. The larval lobsters are kept in the rearing car in the slowly moving current until they have shed their skins 4 times and have reached the fourth state. The length of this larval period is dependent upon many factors, the chief being the temperature of the sea water and the food given the lobsters.

In some cases the young lobsters are not planted until they reach the fifth stage of their development. The degree of success attained by this method is de-

termined by the choice of food, the attention given the equipment, and the temperature of the sea water. The advantage of this method over the others proposed previously lies in its ability to keep the larval lobsters off the bottom from which they are unable to rise and on which they would kill each other. Moreover, the upward moving spiral current of water prevents the young lobsters from congregating anywhere, and thus reduces the losses resulting from their cannibalistic proclivities.

The Federal Government has established lobster hatcheries at Booth Bay Harbor, Me., and Gloucester, Mass. Maine and Connecticut both operate lobster hatcheries, and Massachusetts has plans underway to establish one on Cape Cod, the exact location of which has not been decided upon.

Chemical Composition and Nutritive Value of Lobsters

Fresh Lobsters. Comparatively few analyses have been made of whole lobsters or lobster meat, and those which have been carried out have, for the most part, only considered the proximate composition of the lobster. While carrying out some researches to determine the changes taking place in the composition of lobsters during prolonged fasting Morgulis (1916) analyzed whole normal lobsters. His results are given in Table 137. Atwater (1919) has made an extensive study of the composition of materials commonly used for food in the United States. His analyses of fresh lobster and canned lobster are presented in Tables 138 and 139.

These data indicate that lobster meat contains a negligible amount of carbohydrates and only a small percentage of fat. The dry matter of lobster meat contains approximately 80 per cent protein. Since in eating lobsters about 60 per cent of the animal is discarded and approximately 80 per cent of the remainder is water, the total nutrient content of fresh lobster is only about 7 per cent. At present

TABLE 137. AVERAGE COMPOSITION OF 5 WHOLE LOBSTERS.

Constituent	Fresh material	Water free basis
	%	%
Dry matter	32.672	
Water	67.328	
Organic matter	21.010	64.305
Total inorganic matter	11.662	35.695
Nonvolatile inorganic matter	8.955	27.409
Total glycogen	0.161	0.494
Ether extract	0.954	2.919
Alcohol extractives	1.831	5.605
Alcohol extracted nitrogen	0.145	0.443
Per cent nitrogen in alcohol extract	2.582	7.904
Water extractives	3.285	10.528
Water extracted nitrogen	0.374	1.146
Per cent of nitrogen in water extract	3.558	10.891
Total nitrogen	2.168	6.636
Protein (nonextracted nitrogen $\times$ 6.25)	10.315	31.544
Undetermined	4.464	13.215

Source: Morgulis, S., "Changes in the Weight and Composition of Fasting Lobsters," *J. Biol. Chem.*, 24, 137–147 (1916).

TABLE 138. COMPOSITION OF FRESH LOBSTER.

	No. of Analyses	Refuse	Water	Protein N × 6.25	Fat	Total Carbohydrates	Ash	Fuel Value per lb
		%	%	%	%	%	%	Cal
Edible portion:								
Minimum	5		68.6	11.6	1.5		1.6	345
Maximum	5		84.3	25.4	2.5	0.9	4.0	555
Average	5		79.2	16.4	1.8	0.4	2.2	390
Whole Lobster:								
Minimum	5	44.0	18.0	4.4	0.5		0.6	115
Maximum	5	73.7	47.2	6.7	0.9	0.4	1.0	165
Average	5	61.7	30.7	5.9	0.7	0.2	0.8	140

Source: Atwater, W. O., and Bryant, A. P., "The Chemical Composition of American Food Materials," U. S. Dept. Agr., *Agr. Expt. Sta. Bull.*, **28**, *Revised* (1906).

TABLE 139. COMPOSITION OF CANNED LOBSTER.

	No. of Analyses	Water	Protein N × 6.25	Fat	Total Carbohydrates	Ash	Fuel Value per lb
		%	%	%	%	%	Cal
Minimum	2	76.2	16.7	0.5	0.5	2.1	345
Maximum	2	79.4	19.5	1.7	0.6	2.8	445
Average	2	77.8	18.1	1.1	0.5	2.5	390

Source: Atwater, W. O., and Bryant, A. P., "The Chemical Composition of American Food Materials," U. S. Dept. Agr., *Agr. Expt. Sta. Bull.*, **28**, *Revised* (1906).

prices of lobsters the protein and fat purchased are exceedingly costly. The vitamin content of lobster meat has not been determined, but it is probably relatively high.

Composition of the Shell of the Lobster. The inorganic constituents of lobster shells consist chiefly of calcium carbonate and phosphate and magnesium carbonate. The shells of young lobsters contain a larger proportion of calcium carbonate and a smaller proportion of calcium phosphate than the shells of older lobsters. Clarke and Steiger (1919) analyzed the inorganic constituents, claws, and carapaces of a small, medium, and large lobster. Their results are given in Table 140.

TABLE 140. THE INORGANIC CONSTITUENTS OF LOBSTER SHELLS.

	Small		Medium		Large	
	Claw	Carapace	Claw	Carapace	Claw	Carapace
	%	%	%	%	%	%
Iron, aluminum, and silicon oxides	0.33	0.35	0.36	0.66	0.31	0.57
Magnesium carbonate	10.81	7.74	11.28	8.12	10.99	8.77
Calcium carbonate	72.41	78.98	55.46	70.58	56.89	65.14
Calcium sulfate	1.24	1.23	2.12	1.58	2.32	2.32
Calcium phosphate	15.21	11.70	30.78	19.06	29.49	23.20
Total	100.00	100.00	100.00	100.00	100.00	100.00

Source: Clarke, F. W., and Steiger, G., "The Inorganic Constituents of Lobster Shells," *Proc. Nat. Acad. Sci.*, **5**, 6–8 (1919).

New England Lobster Fishery

Although the number and weight of lobsters caught annually in New England has decreased rapidly during the past 50 years, this fishery is still one of the most important fishing industries of that section of the country. The lobster catch in 1945 is given by states in Table 141. The total number of traps which were licensed in 1945 was 464,826; therefore, the average weight of lobsters taken per trap was 48 pounds in the New England States.

TABLE 141. PRODUCTION OF LOBSTERS BY STATES FOR 1945.

State	Pounds	Value
Maine	17,988,200	$7,361,748
Massachusetts	2,873,900	1,309,546
New Hampshire	823,700	347,954
Connecticut	314,400	154,771
Rhode Island	266,700	133,350
Total	22,226,900	$9,307,369

In Maine the lobster fishery is by far the most important fishing industry of the State; the value of the lobsters caught is about 36 per cent of that of all fishery products landed. The demand for live lobsters has forced the retail price to luxury limits. However, this rapid rise in price has kept the value of the lobster fishery up in spite of the rapidly decreasing annual catch.

The figures given in Table 141 indicate that over half of the New England lobsters are caught in Maine, and that Massachusetts and New Hampshire are also important lobster-producing states.

Some lobsters are also caught in New York, New Jersey, and Delaware, but this industry is comparatively unimportant.

Methods of Fishing. *Pots.* Lobsters are captured in traps called pots or creels which vary greatly in shape and dimensions in different sections of the country, but which operate on the same principle. In general they consist of oblong lath boxes in which bait is placed. These pots have one or more funnel-shaped openings, usually inclined obliquely upward, through which the lobsters pass in their search for food. Once inside the trap relatively few are able to escape through the hole at the small upper end of the net funnel. Some pots have a funnel in each end, while others have an inner compartment reached only through a second funnel.

The type commonly used in Maine has a flat bottom and is semicylindrical in form, being about 4 feet long, 2 feet wide, and 18 inches high. These traps are constructed of ordinary spruce or pine house laths, nailed lengthwise to a hardwood framework. Each end consists of a funnel-shaped coarse meshed net, the larger end of which is the same diameter as the framework of the pot. The smaller and inner end is about 6 inches in diameter and is held open by means of a wire ring or wooden hoop. These funnel-shaped nets are constructed so that when they are in place they lead obliquely upward into the pot. The inner ends are held in position by 1 or 2 cords extending to the center frame. The funnels are about a foot deep and, therefore, extend about half way to the center of the pot. The captured lobsters are removed through a door at the top of the pot. The door

consists of 3 or 4 laths on a frame attached to leather hinges fastened by wooden buttons.

In Rhode Island many oblong slat pots are used. They vary in length from 2 feet 10 inches to 4 feet, and are from 17 to 24 inches wide and from 12 to 20 inches high. Each pot has 2 funnels about 10 or 12 inches deep, made of 2-strand manila twine with 1-inch mesh. The outer funnel, like that of the creel described above, is inclined at an angle of 65 degrees with the bottom of the pot. The smaller opening of the inner funnel terminates in a collapsible hoop of twine which the lobster pushes open as he enters the inner compartment and which closes behind him and shuts off his retreat. The door is usually constructed on the side in this type of pot. The bait is fastened upon a peg or spear which is fixed upright in the inner compartment.

Many other types of pots are in common usage, but space will not permit their description.

In order to keep the pots on the bottom they are weighted down by bricks or stones which are fastened to the bottom on the inside.

Bait. Almost any kind of fresh, salted, or stale fish is used as lobster bait, the choice depending upon the custom in the particular community and on the kind

(*Courtesy Wayne Buxton, Maine Development Commission*)

FIG. 30–2. The salt fish used as bait for the lobster traps is tied to the bottom of the trap so that it cannot float away.

of bait obtainable. Cod, cusk, haddock, and halibut heads are frequently used. Small, lightly salted, partly decayed herring are a favorite bait in certain sections of Maine. Some lobstermen prefer partly decayed bait as they maintain that the odor attracts the lobsters; others prefer fresh bait. Other fish commonly used for bait are menhaden, cod, flounder, sculpin, cunner, sea robin, skate, and scup.

Attempts have been made to develop an artificial bait which can be used to eliminate those mentioned above. This is prepared from materials which give off an odor of decomposing fish. The usual type is compressed into a block and enclosed in a muslin bag which can be fastened in the pot with ease. As the muslin bag protects the bait and prevents it from being scattered by the lobsters, it will last indefinitely. However, fishermen who have used this report that it is not as efficient as natural baits, but does attract some lobsters. Some of these baits have been tried on crabs with similar results.

Fishing. The pots are either set on single warps or on trawls having from 3 to 60 traps. In the early days of the industry all pots were set singly, but the lobstermen discovered that if the pots were attached to trawls, one man could fish alone. When the pots are set singly, one man is usually required to handle the boat while the other hoists the traps, removes the lobsters, and renews the bait. One end of the line, by which the pot is hauled up and lowered, is fastened to the framework of the creel; the other is attached to a buoy which usually consists of a piece of cedar or spruce painted a distinctive color so that each fisherman may easily recognize his own traps. Often 2 buoys are used, one being placed about the middle of the line and the other at its upper end; this prevents the line from fouling on the rocky bottom.

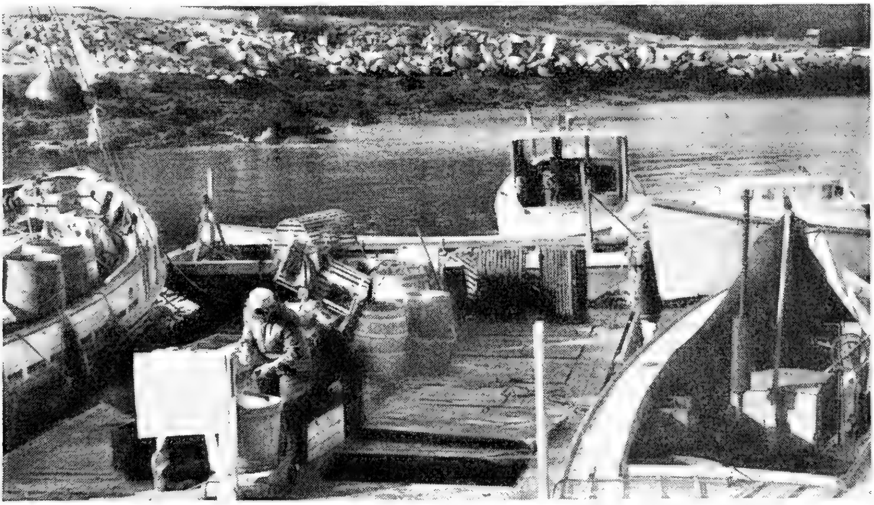
(Courtesy Wayne Buxton, Maine Development Commission)

Fig. 30–3. Sorting lobsters according to size at a float.

The depth at which the pots are placed depends upon the season, the shore, and the nature of the bottom. In winter the lobsters retire to deeper water, usually to the open sea, and are more scattered than in summer when they are found in the shallower water of bays and harbors. Because of this the pots are set further apart in winter and in deeper water further from the shore. In warm weather the traps are set in from 2 to 10 fathoms of water, but in cold weather from 10 to 25 fathoms are necessary. Formerly, very little fishing was carried out in winter, but now many lobstermen continue their operations throughout the year.

Where lobsters are plentiful, the traps are hauled twice daily; but, because of their increasing scarcity in New England it seldom pays the lobstermen to haul their traps more than once each day. As many as 100 pots are often set. The average number of traps set has increased in recent years as the number of lobsters caught per trap has decreased; this increase was necessary in order to maintain at the former level the number of lobsters caught.

Preservation of Live Lobsters. Lobsters are marketed either alive, boiled, or canned. Since boiled lobsters spoil quickly and are therefore often of questionable quality, the greater portion are marketed alive. Each lobsterman has a live-car in which he keeps his catch until they are sold. These cars are usually oblong, rectangular boxes, with open seams or numerous small holes to permit the free



(Courtesy Robert L. Dow, Maine Sea and Shore Fisheries)

Fig. 30–4. The lobster buyers hold the fisherman's catch in "live cars" until they have a sufficient number to ship to the market.

circulation of the sea water. Their average size is about 6 feet long, 4 feet wide, and 2 feet deep. The door through which the lobsters are introduced and removed is on the top. Dealer's cars are quite similar to those used by the fishermen, except that they are much larger; a common size is 30 feet long, 12 feet wide, and 3 feet deep. Such a live-car will hold from 2,000 to 3,000 lobsters, depending upon their size. Dealer's cars are usually divided into several transverse compartments,

each of which is provided with 2 large doors. The lobsters are removed from the cars by means of dip nets attached to long wooden handles. When in use the live-cars are usually moored in a convenient spot close to shore.

Transportation of Live Lobsters. *On Vessels.* A large proportion of Maine lobsters are caught along shores which have no direct rail connections, and they must, therefore, be transported by water either to a market or to a railroad sta-

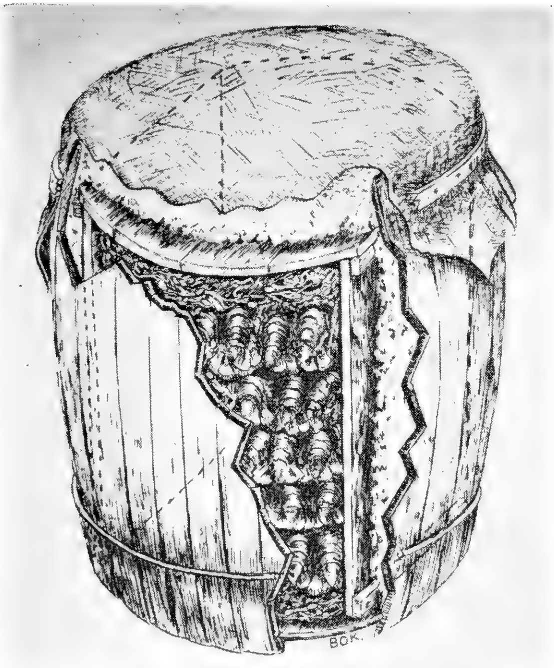


FIG. 30–5. The most usual shipping container for live lobsters for the market. There are some variations of this method in that boxes are used. The general construction and design of them are the same.

(Courtesy U. S. Fish and Wildlife Service)

tion where they are shipped on ice to distant markets. Lobsters which are shipped in smacks are carried in wells, usually between the pilothouse and the enginehouse. Small holes in the bottom of the wells keep them filled with fresh sea water. These well-smacks have regular routes on which they visit various fishermen and purchase the lobsters which they are holding in their live-cars, and transport them to the city markets.

By Rail. Lobsters are expressed by being packed in barrels with ice. Second-hand sugar or flour barrels are ordinarily used as containers. A cake of ice weighing about 100 pounds is split lengthwise into 3 pieces. One of these pieces is placed upright in the center of a barrel and the lobsters are packed snugly all about it. When the barrel is nearly full, the lobsters are covered with seaweed or paper and the rest of the space is filled with cracked ice. A piece of sacking is then placed over the top and fastened under the upper hoop of the barrel (Fig. 30–5).

There are several modifications of this method of packing lobsters for shipment, but they all follow the same general idea. The ice is usually placed in separate compartments so that the water from it will not come in contact with the lobsters. Recently, specially treated corrugated paper cartons have been devised

for both rail and air shipment of live lobsters. These cartons are similar to those made from other materials and have separate compartments for ice.

Boiling. Live lobsters are preferred in nearly all markets, and consequently comparatively few lobsters are boiled before marketing. In many districts retail dealers boil live lobsters for their patrons after their purchase.

Boiled live lobsters will keep for a week if they are packed in ice. Much boiled lobster meat is picked from the shell and sold for the preparation of salads and for other purposes.

The form and size of the boilers used for cooking lobsters vary widely; the large dealers use rectangular tanks or vats, partially filled with water into which steam is passed. The live lobsters are placed in an iron framework basket which is lowered into the tank by means of a small derrick. Small dealers and fishermen use boilers varying in size from an ordinary washboiler to a smaller form of the tank used by the larger dealers. A small amount of salt is usually added to the water, and the lobsters are usually boiled for 20 minutes, or until the proper red color indicates that they are sufficiently cooked.

Canadian and Newfoundland Lobster Fishery

Live Lobster Industry. The methods employed by lobstermen in Canada and Newfoundland very closely resemble those used in the United States. However, the scale of the business is very much greater in Canada than anywhere else in the world. In Nova Scotia alone there are over 3,000 men employed in lobster fishing during the season, and a total of approximately 9,600 are engaged in this fishery in the Maritime Provinces.

Canadian and Newfoundland lobstermen, for the most part, use the same type of pots as those commonly employed in the Maine and Massachusetts fishery. However, the style of traps has changed from those with slats 2 inches or more apart to those which retain nearly all the small lobsters which enter. The dimensions and shape of the pots vary in different localities, depending upon the custom in the vicinity and the ideas of the individual lobsterman; but, as in Maine, the semicylindrical trap with an entrance funnel at either end is most popular.

As in New England the fishermen set their pots in relatively deep water in cold weather and bring them nearer the shore in spring. Since 1874 closed seasons have been established in the different Canadian Provinces. At present the length and time of this closed season varies in different sections of the coast. The open season has been greatly restricted in all the provinces and in some cases has been limited to 6 weeks. The minimum legal length varies from 8 to 10.5 inches in the different provinces; but this law is not strictly enforced. The taking of berried lobsters has been forbidden in Canada since 1873.

The long closed season makes the Canadian lobster fishery a seasonal industry. Thus, all lobstermen engage in other occupations for the greater part of the year; a few of them are farmers, but the greater majority fish during the closed season.

The live lobsters are usually collected from the lobster fishermen in well-smacks by the canners or wholesale dealers. The wholesale dealers transport the lobsters either to the markets in the well-smacks or to a shipping point where they pack them in barrels with ice and ship them to the markets. A large portion of the lobsters marketed alive are exported to the United States, where Portland, Boston, and New York are the most important lobster-importing markets.

Canning of Lobsters

No lobsters have been canned in the United States since 1895 because the Maine law restricting the sale of lobsters less than 10.5 inches long has made it impossible for the packers to obtain large quantities of cheap lobsters. In Canada and Newfoundland laws restricting the use of short lobsters have been made, but have not been strictly enforced; consequently, the canners have been able to operate profitably. The canning industry is conducted on a large scale in the Maritime Provinces. In 1946 71,280 standard cases of 48 pounds each were canned and distributed among the Provinces as follows: Prince Edward Island, 26,323; Nova Scotia, 19,600; New Brunswick, 19,041; and Quebec, 6,316.

The first step in the canning of lobsters is boiling. The live lobsters are usually placed in an iron framework basket which is lowered by means of a small derrick into rapidly boiling water. The boilers in common use are rectangular wooden tanks lined with zinc and equipped with a cover. These tanks are heated by steam which is passed into the water in the boiler through perforated pipes in the bottom. About 3 per cent of salt is usually added to the water used in boiling the lobsters.

After boiling for 20 to 30 minutes the lobsters are cooled in a cold salt solution. When the lobsters are cool enough to handle, the claws and tail are broken off. The body shell is opened, the stomach, liver and coral removed, and the body taken out of the shell. The claws are cracked and the meat is removed whole, if possible. The "arms" are split longitudinally and the meat removed with a fork. The tails are split and the intestine is pulled out.

The meat is packed in several different sizes of C-enamel-lined cans, having a second lining of parchment paper which prevents the meat from coming in direct contact with the tin and being thus discolored. In filling the cans the tails are usually placed in the bottom and the arm-meat and claws on top. Salt is always added, either dry or as brine. Occasionally the lobster is flavored with pepper, bay leaves, and cloves.

The modern procedure is to exhaust the topped cans in a steam box for about 10 to 12 minutes, after which the cans are vented and sealed. The sealed cans are then heated in a retort for 1 hour and 15 minutes at 250° F (121° C). The cans are cooled in cold water, and 48 1-pound cans or 96 half-pound cans are packed in a case.

Frozen Lobsters

Both boiled and raw lobsters are frozen for the market. The meat is often picked from the boiled lobsters and packed in tin cans with a tight cover, or in waxed cardboard cartons for freezing. The whole lobsters are sometimes frozen and packed in individual waxed cartons. It has been reported that frozen raw lobsters retain the quality better than those which have been boiled. The deterioration of the meat which has been cooked results in a toughening and loss of flavor on long storage. There is often considerable breakage of lobsters which are frozen whole. When frozen they are very brittle and the legs snap off easily unless they are handled with considerable care. In order to reduce breakage the lobsters are usually packed in cartons before they are frozen.

Live Lobsters in Hermetically Sealed Cans

A method known as the "Live Pak" is being promoted for handling live lobsters. It is reported that this development has covered a period of approximately 3 years, and is suggested that it may be particularly applicable to those markets situated at points distant from production areas.

In the commercial application of this method 2 live lobsters are packed in a 2-gallon tin can, about ⅓ full of fresh synthetically prepared sea water. A pellet of a chemical mixture, of secret formula, is added to furnish oxygen and destroy waste materials. The lids of the cans are hermetically sealed and the cans are then packed in ice or some other refrigerant for shipment. It is stated that the cans must be refrigerated to a temperature of 40° F (4.4° C) in order that the contents reach their destination in good condition. At this temperature the metabolism of the lobsters is at a minimum and they are able to remain alive for at least 6 days; in some shipments it has been found that they remain alive as long as 16 days.

In conjunction with this development tanks for use in stores have been designed which will hold from 700 to 8,000 pounds of live lobsters for display and sale. In the case of handling large quantities of live lobsters for air transport to retail stores a container for 250 pounds of live lobsters has been designed. This container is made of aluminum and is so constructed that a spray of synthetic sea water is played on the lobsters each 25 minutes during transit. It is recommended that the temperature of this container also remain 40° F (4.4° C) during transit.

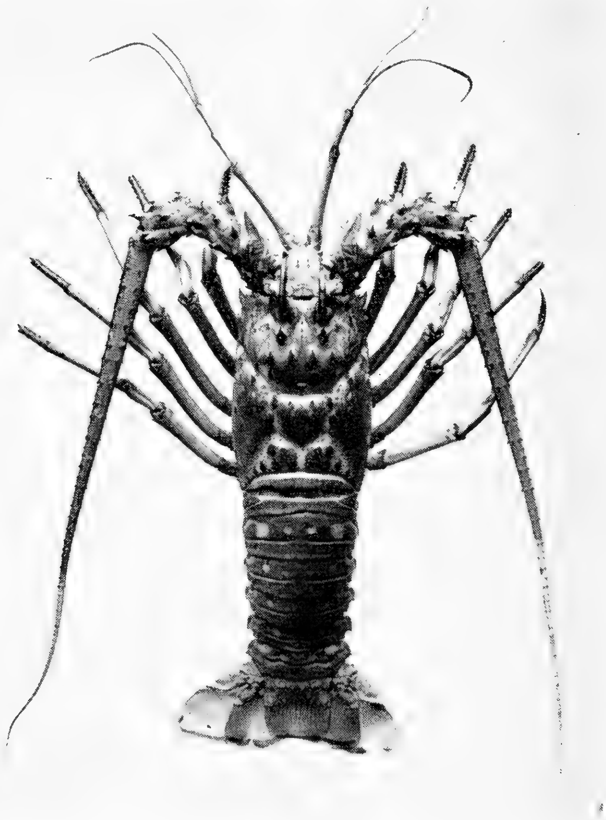
United States Spiny-Lobster Fishery

The spiny lobster or sea crayfish is found in the warmer waters throughout the world. While it is related to the true lobster, there are several distinct, easily recognized differences: It does not have the large heavy claws, which are one of the distinguishing characteristics of the true lobster; it is covered with spines on both body and legs, which accounts for its name; and it has long slender antennae. Smith (1948) states that there are two species found in the United States: *Panulirus argus* ranges from Beaufort, N. C., south to Rio de Janeiro, Brazil and is caught chiefly in the Florida Keys; and *Panulirus interruptus* ranges from Oregon south. It is usually found in the kelp beds in cold weather and migrates to more shallow water during warm seasons. Florida and California are the principal producing areas. In 1945 Florida produced 777,100 pounds, valued at $157,-427; while in California the production was 479,100 pounds, valued at $114,812.

Other species of spiny lobster are caught in Hawaii, the Philippine Islands, Japan, Australia, and South Africa. Considerable quantities are imported into the United States from South Africa and the Caribbean Islands. The imports are composed of the large muscular tails, frozen as a means of preservation.

In Florida the closed season is March to July, and it is illegal to take them less than 9 inches long and about 1 pound in weight. In California the fishing season extends from October to March 16. It is reported that spiny lobsters weighing from 4 to 6 pounds are fairly common in the California area. Those caught in Florida are usually between 1 and 2 pounds in weight. The best fishing grounds in Florida are along the southern shores of the reefs and keys extending from Boca Grande Key on the west to Sugar Loaf Keys on the east.

About half of the catch in Florida is taken in bully nets, the remainder is caught with traps, grains, hoop nets, seines, and hooks. The "bully" is a small hoop net, 15 to 18 inches in diameter, 2 feet or more in depth, and with mesh of 1¼-inch bar measure. It is used chiefly in water 10 feet deep or less where the bottom can



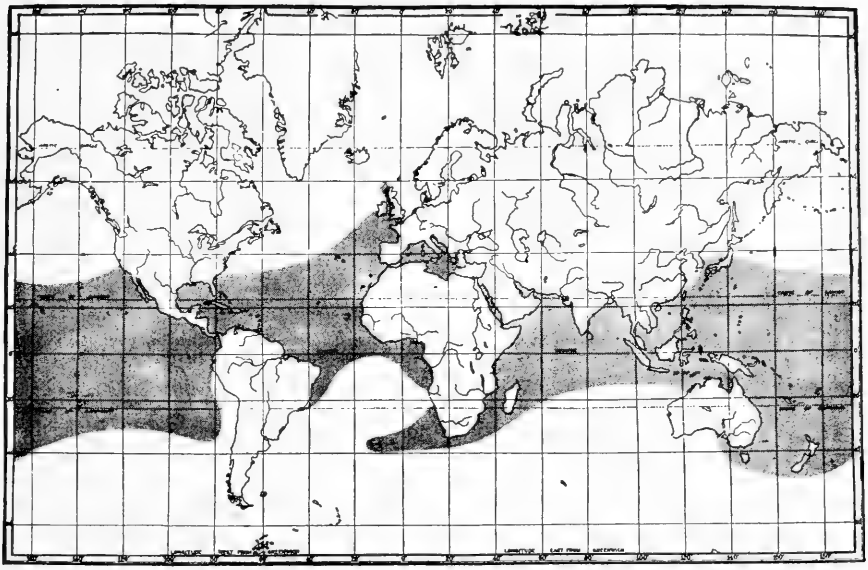
(Courtesy U. S. Fish and Wildlife Service)

Fig. 30–6. The spiny lobster or sea crayfish (*Panulirus interruptus*).

be seen. The fishing is better at night, as during the day many lobsters conceal themselves under rocks, sponges, and corals. At night a lamp similar to a street lamp is fastened to the bow of the boat, thus enabling the fisherman to examine the bottom. Traps constructed of galvanized-iron wire are commonly used for catching the spiny lobsters in deep water. This is the chief source of supply during the summer months when the lobsters retire to deeper water.

Crawford and de Smidt (1923) have described the marketing of the Florida crayfish as follows:

"The spiny lobsters are taken to the local markets alive, having been kept in the wells where there was a free circulation of water. . . .



(Courtesy U. S. Fish and Wildlife Service)

FIG. 30–7. The distribution of spiny lobsters (*Palinuridae*).

"At the market the catch is sorted, counted, and transferred to floating cars or inclosures where it is kept until ready for shipment. Spiny lobsters which have died and those in a dying condition are sold as bait to the hook-and-line fishermen. The market value varies from $0.75 to $2 per dozen, according to season, demand, and size. The average price obtained by the fishermen is $1 per dozen. The dealers sell by the pound. The average spiny lobster weighs about 1½ pounds.

"During cool weather spiny lobsters shipped to points in southern Florida are simply placed in wet sacks, and under such conditions they will live 4 or 5 hours. If properly packed they will live from 2 to 3 days. During the winter and spring months many spiny lobsters are shipped as far north as Philadelphia, New York, and Boston. They are packed in barrels containing alternate layers of ice and shellfish.

"The method of packing is the same as that employed in preparing fish for shipment, except that a layer of sponge clippings or seaweed separates the shellfish from the ice. The average barrel will hold from 10- to 12-dozen spiny lobsters."

Spiny Lobster Trade.[1] "The trade in spiny lobsters in the United States is based mainly on imports since the domestic production of this species has been for several years not more than 1,000,000 pounds (Table 143, p. 651).

"Before the war the Union of South Africa, Mexico, Cuba, and the Bahamas were the only shippers of fresh and frozen 'lobsters' (spiny lobster). The imports reached a maximum of 5.6 million pounds in 1941. By 1945 this dropped to around 3.3 million pounds. Starting with 1946 imports increased so that over 6,000,000 pounds were shipped to this country during 1946 and 1947 and 7,755,000 pounds in 1948. Besides the 4 principal prewar sources imports have been received from 9 other countries. Within the past year, Australia has entered the export market with frozen spiny lobster tails,

[1] From Chace, F. A., Jr., and Dumont, W. H., "Spiny Lobsters: Identification, World Distribution, and U. S. Trade," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **11,** No. 5, 1–12 (1949).

TABLE 142. PRODUCTION OF SPINY LOBSTERS BY COUNTRIES.

Country	Year	Production Pounds
North and Central America:		
United States:		
Atlantic Coast	1944	463,000
Pacific Coast	1944	513,000
Mexico	1947	3,000,000
Guatemala	1947	200,000
Br. Honduras	1947	700,000
Cuba	1945	6,700,000
Bahama Islands	1947	1,400,000
Europe:		
France	1937	710,000
Ireland	1946	30,000
Portugal	1944	383,500
Spain	1946	720,000
United Kingdom	1946	400,000
Africa:		
Algeria	1940	62,500
Fr. Morocco	1938	66,000
Tunisia	1939	40,000
Union of So. Africa and Southwest Africa	1947	25,000,000 [1]
Mauritius	1947	50,400
Australia	1946	4,577,000
New Zealand	1947	1,985,700
Japan	1946	4,850,000

[1] Production limited by Union of South Africa to 6,000,000 lbs of tails for canning or freezing for export. This is equivalent to 18 million lbs of whole spiny lobsters. Local consumption is around 2 million lbs, while the production in Southwest Africa is estimated to be around 5 million lbs.

Source: Chace, F. A., Jr., and Dumont, W. H., "Spiny Lobsters: Identification, World Distribution, and U. S. Trade," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **11,** No. 5, 1–12 (1949).

and is now in fourth position as shipper to this country. The large proportion of imports of frozen spiny lobster tails has been from South Africa and Australia, with some from Cuba and the Bahamas. Whole spiny lobsters—live, boiled, and iced—are imported from nearby islands and countries. The import data do not separate the tails from whole spiny lobsters. However, it is known that all the imports from the Union of South Africa, Australia, and New Zealand are tails. As the tail represents about ⅓ of the live animal, the imports from these 3 countries, although only 40 per cent of the total import weight, represent nearly 10,000,000 pounds of live spiny lobsters, or over 2 times the combined imports from all the countries of the western hemisphere.

"The South African tails are generally individually wrapped in cellophane before freezing. After grading into sizes they are packed in flat slat boxes, holding 20 pounds each. The sizes are: ½-pound to ¾-pound; ¾-pound to 1-pound; and over 1-pound.

"The shipment of fresh, frozen, and cooked spiny lobsters from Mexico, Cuba, and the Bahamas is dependent on the legal seasons in those countries. The large proportion of imports from Mexico are shipped from November to March (Table 144). The

TABLE 143. U. S. IMPORTS OF FRESH, FROZEN, AND COOKED SPINY LOBSTERS (Whole and "Tails").

Country of Origin	1948 Lbs	1947 Lbs	1946 Lbs	1945 Lbs
Mexico	2,052,491	1,920,442	1,671,234	1,072,935
Honduras	6,606			
Br. Honduras	136,264	157,538	79,220	
Nicaragua	406			
Bahamas	1,197,821	1,371,701	1,271,677	1,487,634
Cuba	1,150,792	425,201	250,100	353,881
Jamaica	7,150	53,376		
Leeward Islands	2,085	13,587	3,500	
Curacao		1,878		
Fr. W. Indies		7,040	7,004	
Australia	514,290	97,482		
New Zealand	30,410	29,256		
Union of So. Africa	2,657,178	2,236,780	2,564,345	433,600
Total	7,755,493	6,314,281	6,847,080	3,348,050

TABLE 144. MONTHLY INDEX OF U. S. IMPORTS OF SPINY LOBSTER TAILS. (From the Principal Countries)

Country from Which Imported	Quantity Imported in 1948 (lbs)	Per cent Received per Month, 1948												
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Mexico	2,082,491	22	26	14	1	1	1	1	1	1	2	12	18	100
Br. Honduras	136,264	20	1		2	12		3			12	44	6	100
Bahamas	1,197,821	7	19	16	3						9	28	18	100
Cuba	1,150,892	2	4	5	1	4	5	8	9	10	19	17	16	100
New Zealand	30,410	3		13		1			7	20		56		100
Australia	514,290			38	7	4	21			21		1	8	100
Union of So. Africa	2,657,178		16	11	6	10		15	1	10	5	13	13	100
Total	7,755,593	7	16	13	4	5	2	7	2	7	7	15	15	100

Note: Honduras, Nicaragua, Jamaica, and Leeward Islands were not included in the index since their shipments were insignificant.

season for the Bahamas runs from October to March, while Cuba's shipping period is longer—July to December, with smaller amounts coming in during January, February, and March. Shipments of frozen spiny lobster tails from South Africa may be made throughout the year. The bulk of the shipments were made from December to May in 1947, but in 1948 there was no outstanding month.

"In prewar years over 400,000 pounds of canned spiny lobster meat from Cuba, Union of South Africa, and the British West Indies were imported into the United States. During 1945 and 1946 Cuba was the only shipper and exported to the United States over 450,000 pounds of canned meat. The imports dropped drastically in 1947, when only 136,509 pounds of spiny lobster meat entered this country. However, imports for 1948 more than doubled the 1945 imports and amounted to 1,037,710 pounds, with South Africa again leading. Small quantities were shipped from New Zealand, Guatemala, and China (Table 145, p. 652)."

TABLE 145. U. S. IMPORTS OF CANNED SPINY LOBSTER MEAT.

Country of Origin	1948 Lbs	1947 Lbs	1946 Lbs	1945 Lbs
Cuba	294,546	122,359	461,529	459,375
Guatemala	1,238			
New Zealand	19,175	12,825		
Union of So. Africa	722,151	1,325		
China	600			
Total	1,037,710	136,509	461,529	459,375

Freezing Spiny Lobster Tails. When the live lobsters are landed at port, they are stored in a cool room until needed. When they are prepared for freezing, the tails are broken off and the intestines removed by pulling them out through a small cut in the tail. They are washed in either fresh or chlorinated water, graded according to size, wrapped in a moistureproof wrapper, and packed in waxed cardboard cartons containing 5 pounds each. After the cartons are frozen, they are packed into a large corrugated paper carton, with a capacity of 6 small cartons. The large carton is sealed and stored at $-5°$ F ($-24.4°$ C) for future shipment to market. Some frozen meat which is imported from Cuba is packed in ¼-pound tin cans with a cellophane window in the top.

European Lobster Fisheries

Development of the Fishery. Although lobsters have been known to people of Northern Europe since early times, they were seldom eaten by the fishermen until recent times. Since about 1800 the lobster industry has become an important fishery in Norway and the British Isles. One of the earliest methods of taking lobsters was by hooking them under the body with a hook fastened on a long pole. In the early days of the industry tongs were commonly used in shoal water by fishermen in small boats. These methods of fishing are applicable only in shallow water where lobsters are plentiful, and they usually injure the lobsters so that they cannot be transported any great distance to market. The first important improvement in methods of lobstering was the use of the "plumper." This trap consisted of an iron ring to which a net was fastened so as to form a deep bag; bait was placed near the bottom of the bag. Such traps had to be carefully watched and pulled very often as the lobsters could escape easily. At present cylindrical traps or creels are largely used; they operate on the same principle as those used in New England and Canada, but differ chiefly in shape. They are commonly small cylinders, made of a wooden hoop frame covered with netting, with entrance funnels in both ends. They are usually anchored by means of flat stones tied to the bottom.

Species of Lobsters Caught in European Waters. The American lobster (*Homarus americanus*) is not found on the coast of Europe. The true European lobster is *Homarus gammarus;* it closely resembles the American lobster, but is distinguished by the narrower spine on its forehead and by having teeth only on its upper margin. The langouste (*Palinurus vulgaris*) is commonly found on the coast of France and Spain and in the waters of the Mediterranean; this crustacean is sometimes called "crawfish of the sea," "thorny lobster," "spiny lobster," "rock

lobster," and "red crab"; it is not a true lobster though it is often classed with lobsters. In Great Britain it is commonly called the "thorny lobster." Although it has been found in various localities along all the coasts of the British Isles, it is common only on the southwest coast of England. The langouste is much esteemed as an article of food although considered of inferior flavor to the lobster. A closely related species is found on the American coast from California to Mexico and along the Gulf Coast of Florida.

Present Extent of the European Fishery. Although the lobster fishery is an important industry in Norway and the British Isles, it is very small when compared to the American fishery. The latest available figures regarding the British lobster industry indicate that production in 1946 was 823,400 animals, valued at 148,633 pounds.

Lobsters are very high-priced in Europe, particularly in France. Many attempts have been made to export live lobsters from the United States to England, but this has never proved financially successful because of the large losses en route. Large numbers of Scandinavian lobsters are sold in England. Many of the lobsters caught in the British Isles are exported to France.

The high price of lobsters in Europe has made canning unprofitable; consequently, practically all that are taken are sold alive.

REFERENCES

Ackerman, E. A., "New England's Fishing Industry," Chicago, University of Chicago Press, 1941.

Allen, B. M., "The Problem of the Spiny Lobster, *Panulirus interruptus*," California Fish and Game Commission, *Fish. Bull.*, **1**, 18–26 (1913).

Allen, B. M., "Notes on the Spiny Lobster *Panulirus interruptus* of the California Coast," *Univ. of Calif. Pub. in Zoology*, **16**, No. 12, 139–152 (1916).

Anon., "For Inland Oceans," *Industrial Bull.*, No. 261, 1, Cambridge, Mass., Arthur D. Little, Inc. (Jan., 1950).

Atwater, W. O., "Chemical Composition and Nutritive Values of Food Fishes and Aquatic Invertebrates," *U. S. Fish Comm. Rept.*, 679–868 (1888).

Carson, R. R., "Food from the Sea-Fish and Shellfish of New England," U. S. Fish and Wildlife Service, *Conservation Bull.*, **33** (1943).

Chace, F. A., Jr., and Dumont, W. H., "Spiny Lobsters–Identification, World Distribution, and U. S. Trade," U. S. Fish and Wildlife Service, *Commercial Fishery Review*, **11**, No. 5, 1–12 (1949).

Clark, F. W., and Steiger, G., "The Inorganic Constituents of Lobster Shells," *Proc. Nat. Acad. Sci.*, **5**, 6–8 (1919).

Cobb, E. W., "Improved Equipment for Lobster Rearing," *Am. Fisheries Soc. Trans.*, 84–87 (1933).

Crawford, D. R., and Desmidt, W. J. J., "Spiny Lobster, *Panulirus argus* of Southern Florida, Its Natural History and Utilization," U. S. Bureau of Fisheries *Bull.*, **38**, 281–310 (1921–22).

Down, L., "The Story of the Maine Lobster," Augusta, *Bull. of Dept. of Sea and Shore Fisheries* (1949).

Firth, F. E., and Knake, B. O., "Construction and Operation of Lobster Fishing Gear," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **64** (1944).

Herrick, F. H., "Natural History of the American Lobster," U. S. Bureau of Fisheries *Bull.*, **29**, 149–408 (1909).

Mead, A. D., "A Method of Lobster Culture," U. S. Bureau of Fisheries *Bull.*, **28**, 219–240 (1908).

Morgulis, S., "Changes in the Weight and Composition of Fasting Lobsters," *J. Biol. Chem.*, **24**, 137–146 (1916).

Nigrelli, R. F., "Lobster Hatcheries to the Rescue," *New York Zoological Soc. Bull.*, **39**, 6, 223–229 (1936).

Pearson, J. C., "Spiny Lobster," U. S. Fish and Wildlife Service, *Fishery Leaflet*, **142** (1945).

Rich, W. H., "Fishing Grounds of the Gulf of Maine," *U. S. Comm. Fisheries Rept.*, **1929**, 51–117 (1930).

Scheid, R. C., "Life to the Lobster," *Modern Packaging*, **23**, No. 10, 100–102 (June, 1950).

Schmitt, W. L., "Early Stages of the Spiny Lobster," *California Fish and Game*, **5**, No. 1, 24–25 (1919).

Schroeder, W. C., "Fisheries of Key West and the Clam Industry of Southern Florida," U. S. Bureau of Fisheries, *Doc.*, **962** (1923).

Smith, F. G. W., "The Spiny Lobster Industry of the Caribbean and Florida," Coral Gables, Florida, Marine Lab. Univ. of Miami, 1948.

CHAPTER 31

Marine Turtles and Terrapins

Introduction

Soups and broths prepared from turtles and terrapins have been highly prized by epicures from earliest historical times. During the colonization of the United States turtles were found highly valuable on long voyages or when a shortage of food occurred. Captain John Smith stated that, "twenty tortoises have been taken in a day, and some of them will afford half a bushel of eggs, and suffice to feed forty men at a meale." It has been reported that in colonial times some specimens caught in the West Indies weighed as much as 850 pounds. Fishing was so intense in this area that it was necessary to limit the locations in which the turtles could be caught and the size of those which could be taken. In Bermuda in about 1620 the taking of turtles within 5 leagues of the island and "under 18 inches in breadth or diameter" was prohibited. The penalty for violation of this law was a fine of 15 pounds of tobacco.

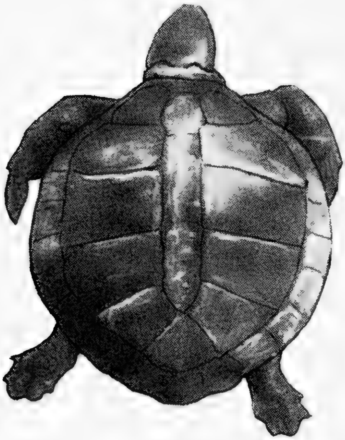
At present considerable quantities of turtles are imported into the United States. Although the greater portion of them are used in the preparation of soup, a few steaks are sold to those who prefer the meat. The latest statistical reports indicate that in 1945 827 cases of 48 standard 15-ounce cans of terrapin and turtle meat, valued at $27,014, were canned. In the same year 9,226 cases of the same size and number of cans of soup, valued at $116,589, were prepared. However, only 6 plants were in operation.

Location and Importance of Industry

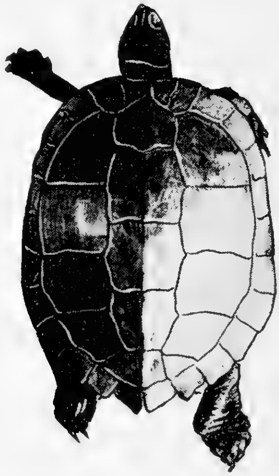
The 3 most important species of true marine turtles are the green turtle, the hawksbill turtle, and the loggerhead turtle. Although the luth or leathery turtle, found on the coasts of Florida and Brazil, is also a true marine turtle, it is of minor commercial importance. The diamondback terrapin, which is such a valuable commercial article, is not a marine turtle in the strictest sense of the word, but a water tortoise; it closely resembles land tortoises although it lives chiefly in saline river estuaries and salt marshes.

Of the 3 important species of marine turtles the green turtle is the most edible. Its flesh is prized, especially for the making of turtle soup, by the large hotels and canneries of North America and as a source of meat supply to the inhabitants of the West Indies and Central America. The hawksbill turtle is the source of the tortoise shell of commerce, and is used only to a limited extent for soup and steaks.

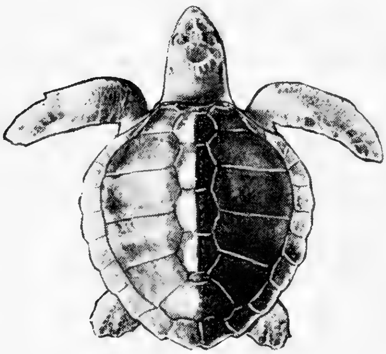
Marine turtles inhabit the tropical and semi-tropical seas at all seasons, and in summer a few are found in temperate seas as far north as New England. In the United States marine turtles are found chiefly in the Gulf of Mexico. The statistics in Table 146 (p. 657), concerning the catch of turtles and terrapins in the



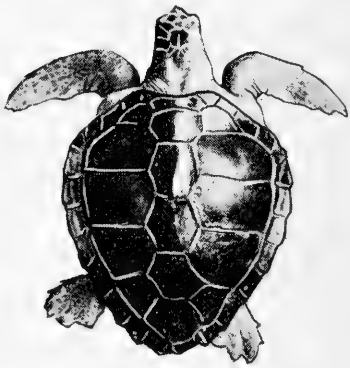
Green Turtle



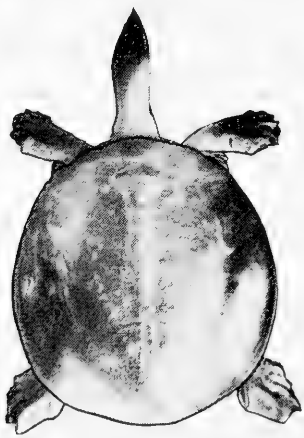
Diamond Back Terrapin



Hawksbill Turtle



Loggerhead Turtle



Softshell Turtle

FIG. 31–1. Turtles and terrapin of commercial importance.

United States in 1945, show that the industry is only of slight importance. Cuba, Yucatan, Mexico, Costa Rica, Nicaragua, and the West Indies possess the largest turtle fisheries. In Brazil many turtles are caught near the mouth of the Amazon River.

TABLE 146. PRODUCTION OF TURTLES AND TERRAPIN, 1945.

Type	Pounds	Value
Terrapin	413,800	$122,650
Green turtles	22,100	2,675
Loggerhead turtles	22,400	2,380
Snapping turtles	266,600	35,338
Soft shell	195,000	15,600

Source: U. S. Fish and Wildlife Service.

The Green Turtle Fishery

The green turtle (*Chelonia mydes*) is the only true marine turtle that is commonly eaten. Its fat is a greenish color, and this characteristic has given it its popular name. The shields of the carapace are smooth and are brown, mottled with yellow and fringed with white or yellow. Although the shell is attractively colored, it has no commercial value. This turtle attains a length of 3 to 4 feet and a weight of 300 to 500 pounds. It is omnivorous, but feeds largely on a marine vegetation known as turtle grass. This turtle lives almost entirely in the sea and never comes ashore, except on brief trips to lay its eggs. As the plastron is not rigidly constructed, it will not support the weight of the turtle when it is on land; because of this the turtles soon die if they are not turned on their backs when out of the water. The excessive weight of the body on the circulatory and respiratory organs causes its death by smothering.

The chief green-turtle fishery of the United States is in the vicinity of Key West, Florida. At present, chiefly because of overfishing, the catch of green turtles on the Florida coast is very small and many more are caught in the West Indies and off the eastern Nicaragua and Costa Rica coasts. However, practically all of the green turtles shipped into the United States are first landed at Key West.

The catching of sea turtles is largely a vessel fishery, schooners or sloops being employed. The most popular form of gear is the gill net. The fishing season is from March to September, inclusive. Many female turtles are caught when they come onto the sandy beaches to lay their eggs. This has the effect of reducing the population when they are taken before the eggs are laid.

Key West Turtle Industry. Shipments of live turtles are made to New York on coastwise steamships, and are usually consigned to Fulton Market, from which they are distributed to other centers. New York imports only part of its green-turtle supply from Key West as many are brought by steamship directly from the West Indies and Central America. The turtles vary slightly in value according to size: Those under 100 pounds command the highest price, while those 200 pounds and over receive the lowest. In 1948 imports were 794,429 pounds of live turtles of all species, valued at $56,933.

One dealer and one cannery handle all of the green turtles brought into Key West. The turtles are landed by schooners, known as "turtle boats," and are placed in pens made of closely spaced palmetto logs; they are able to live indefinitely

thus. In an enclosure about 40 by 70 feet, divided into several smaller enclosures, as many as 500 or more large turtles have been kept at one time.

When a turtle is to be taken from the pen, a rope noose is dangled in the water until it catches the flipper of a turtle as it comes up to breathe. The rope is at

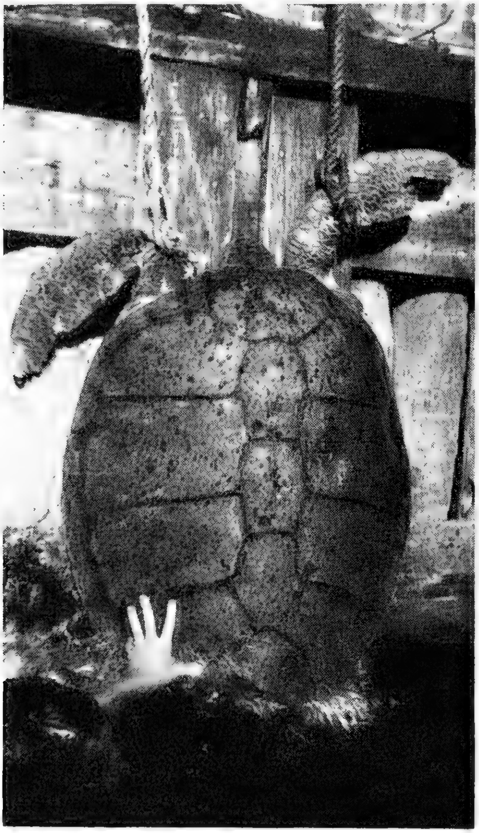


Fig. 31–2. A green turtle being hoisted from the pound to prepare for shipment.

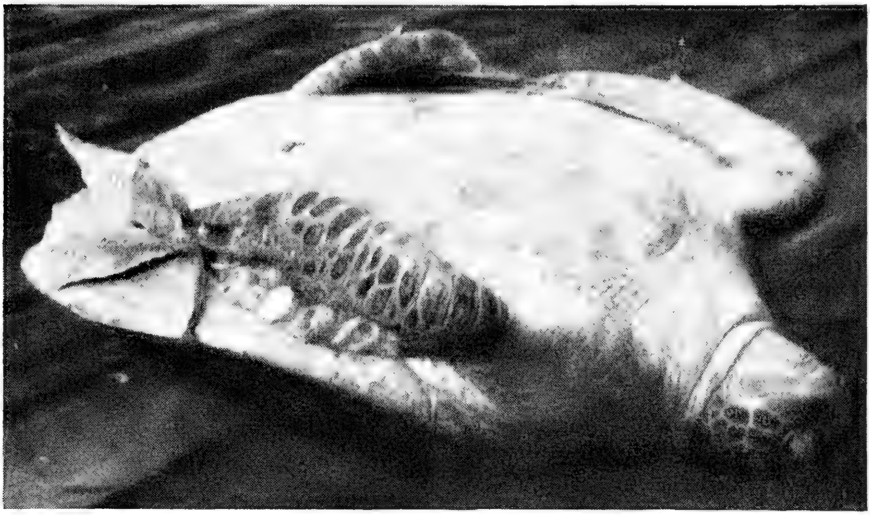
(Courtesy U. S. Fish and Wildlife Service)

once hauled taut and the animal is hoisted to the dock, the precaution being taken to render it helpless by turning it on its back before the noose is cast loose. Turtles are shipped lying on their backs, and to prevent their righting themselves all 4 limbs are bound together by a rope yarn passed through a hole punched in each flipper. This method of keeping them overturned is necessary, though deemed cruel; but the piercing of the flippers is not absolutely essential and may be eliminated.

Turtles to be used for canning are slaughtered on the dock each day at 3:30 P.M., when an inspector is present to see that the butchering is done in a correct and sanitary manner. None is killed until the desired number has been removed from the pens and placed about 1 foot apart on the dock. One person rapidly strikes the head and 4 flippers of each turtle with a sharp axe, nearly severing each. Two men with sharp knives then dexterously cut away the plastron and remove the entrails; water is thrown on the carcasses during the operation to wash away

the blood and slime. The flesh is then cut from the carapace, thrown into a barrel of light salt brine where it is washed, and taken to the cannery where it is hung up overnight before being used. The following morning a small portion of the meat is sold to the public as turtle steaks and the remainder is canned as turtle soup and turtle meat.

The carapace is used by some canners in the preparation of soup stock. It is first scalded in hot water to remove the outer protective plates, then cut up into



(Courtesy U. S. Fish and Wildlife Service)

Fig. 31–3. Green turtle trussed up ready to transport to market.

pieces and boiled in a kettle of water until a heavy liquor is obtained. A small amount of this liquor is added to each batch of soup as it is prepared. However, a few canners and soup makers prefer a stock made from beef bones but the turtle carapace is generally considered to have a superior flavor. Each canner has developed his own particular recipe, the ingredients and proportions of which he is very reticent about revealing. A small quantity of the soup stock is usually added to each can of turtle meat before the can is sealed.

During May, June, and July the females contain both mature and immature eggs, and are greatly enhanced in value because of the demand for the eggs. The white or mature eggs sell at a lower price than the yellow or immature eggs which are sold by the pound and are considered a great delicacy. A female is said to carry from 6 to 30 pounds of eggs according to its size and condition. The white eggs are about the size of a golf ball and the parchment-like shells do not break if dropped from a considerable height.

Costa Rican Fishery. On the Costa Rican and Nicaraguan coasts the turtles are captured principally when they come ashore at night to deposit their eggs. "Turtling" is done before daybreak by men armed merely with lanterns. The turtles are simply turned over on their backs, and are thus rendered helpless.

When the beach has been thoroughly searched and all the turtles secured, the captives are ingeniously made to transport themselves to the turtle launch or

schooner which cruises along the coast at a safe distance offshore; this is accomplished by fastening to one of the turtle's flippers or front legs a piece of strong line about 10 feet long, to the other end of which is attached a float or buoy of balsa wood. The turtles are then turned over on their bellies and allowed to scramble off into the water; they of course promptly head for the open sea, but being hampered by the wooden float make slow progress. When they have cleared the surf, the floats are picked up by the turtle boat. The lines are hauled in and the turtles at the other end are hoisted aboard by means of block and tackle. The turtles are then brought to port where they are placed in crawls or pounds and kept until marketed.

The average green turtle catch is about 750 per year, and about the same number of hawksbill turtles are taken. Green turtles are shipped to New York, Key West, Colon, Panama, Kingston, and Jamaica; the Caribbean islands of San Andres and Providence (belonging to Colombia) are also important markets. The average weight of a female green turtle is about 200 pounds; but they are taken at all weights from 100 to 500 pounds, and in 1945 they sold for approximately 80 cents per pound. There is a greater demand for females than males, and the greater portion of all the turtles shipped are females. Turtle meat is always obtainable in the local markets. The meat is known as "calipash," which is the fatty greenish flesh from the belly; the meat is also dried and, more rarely, smoked.

The Hawksbill Turtle Fishery

The chief source of tortoise shell is the shields of the carapace of the hawksbill turtle (*Chelonia imbricata*). This turtle is the smallest marine turtle and seldom reaches a length of more than 30 inches although 34-inch shells have been found. It may easily be distinguished from other marine turtles by the arrangement of the shields of the carapace which coarsely overlap like shingles. These shields are transparent and are beautifully mottled black or brown and yellow. The shields of the head and limbs are brown or black tinged with pale yellow about their margins. Thirteen plates cover the carapace, 5 occupying the center and 4 on each side. These overlap each other to nearly ⅓ of their whole size. The plates on the larger turtles measure approximately 8 by 13 inches and weigh about 9 ounces. The carapace also has 12 pairs of marginal shields, which form a strongly serrated sharp edge on the posterior half of the shell. The small marginal shields and the plates of the plastron are inferior in value to the larger shields.

These turtles are found in nearly all parts of the tropical and semitropical seas. The best grades of tortoise shell are obtained from the Eastern Archipelago in Pacific waters, particularly from the east coast of the Celebes group to New Guinea. Large quantities of these turtles are also taken in Brazil and in the West Indian Islands, but the shells obtained are considered less valuable.

Manufacture of Tortoise Shell. The shields are removed from the shell of the live or freshly killed turtle either by immersion in boiling water or by heating over a hot fire. Tortoise shell is worked in the same manner as horn; but, since it is more costly, greater care must be taken in its treatment. When the plates are first removed, they are keeled and curved and irregular in form. They are first flattened by heat pressure. As high heat tends to darken the shell, the shell must be treated at as low a heat as possible. Tortoise shell can be welded when hot by pressing the pieces together in a vise. The heat softens and partially liquefies

a superficial film of the shells, which may then be united by sufficient pressure.

Tortoise shell has been highly prized for ornamental purposes since early times. It was one of the treasures brought to Rome through Egypt from the Far East. At present tortoise shell is used in the manufacture of valuable inlaid work, toilet articles, knife handles, and various other ornaments.

The horny shields of the carapace of various other turtles are sometimes used as tortoise shell, but they are poor imitations as they are either opaque or soft and leathery.

The flesh of the hawksbill turtle is eaten to a slight extent, but it is not highly regarded.

The Loggerhead Turtle

The loggerhead turtle (*Thalassochelys caretta*) is the common marine turtle found along the Atlantic Coast from New York southward, and is abundant from North Carolina to Florida. It is of little economic value; the eggs are commonly eaten, but the meat is only occasionally used for food. The shields of the carapace are opaque and therefore of little value.

The larger loggerhead turtles have a shell, about 3.5 feet in length, which is uniformly brown above and yellowish below. This turtle has 5 pairs of costal shields and usually 23 marginal shields. The head is much larger and coarser than that of the green turtle. A carnivorous reptile, the loggerhead turtle lives chiefly on fish.

Along the South Atlantic Coast and the West Coast of Florida this turtle comes ashore at night during the early summer to lay its eggs. From 60 to 160 eggs are laid in the "nest" at one time. These eggs, which are about half the size of hen's eggs, are sold locally, but are rarely shipped. The eggs are found by probing the turtle tracks in the sand until a nest is discovered. The egg shells are only slightly calcareous and are therefore soft. Since the contents do not completely fill the shells, there is always a dent in the egg.

Loggerhead turtle meat is eaten by the fishermen along the coasts where it is found, but only small quantities are shipped.

Other Marine Turtles

The Kemp's Gulf turtle (*Thelassochelys colpochelys kempii*) is found in the Gulf of Mexico and on the Atlantic Coast as far north as North Carolina. Although it is eaten along the coast where it is found, it has no commercial value. Many persons consider the meat superior to that of the loggerhead and nearly as good as that of the green turtle.

The luth or leathery turtle is found along the coasts of Florida and Brazil. This turtle derives its name from the absence of the horny shields which are found on other marine turtles and from the leather-like skin which covers the bony carapace. The leathery turtle attains great size; specimens have been found which were about 8 feet long and weighed over 1,600 pounds. There is a large production of these turtles in Florida.

The Diamondback Terrapin

The diamondback terrapin is undoubtedly the most valuable marine delicacy marketed in the United States. Six-inch terrapins often sell for as much as $60 a

dozen, and larger ones command higher prices. They possess highly esteemed edible qualities and are very scarce.

Diamondback terrapins are found chiefly in salt or brackish marshes near the coast, and were abundant at one time. These terrapins belong to the genus *Malaclemys*, having 4 species and 1 subspecies: the Carolina terrapin (*Malaclemys centrata*), with a range extending from central North Carolina to Florida; the Chesapeake terrapin (*M. centrata concentrica*), which occurs in Chesapeake Bay southward to the North Carolina sounds and northward to Buzzards Bay; the Florida terrapin (*M. macrospilota*), along the Gulf coast of Florida; the Louisiana terrapin (*M. pileata*), which inhabits the coast east and west of the mouth of the Mississippi River; and the Texas terrapin (*M. littoralis*), which occurs along the coast of Texas and southward.

Although terrapins were once plentiful in the salt marshes along the Atlantic Coast, relatively few are found in that locality at present. The fishery is centered in Maryland and Virginia; in 1945 those states produced terrapin valued at $114,875.

Habits and Propagation. Because of the threatened extinction of this valuable aquatic animal the U. S. Bureau of Fisheries (now Fish and Wildlife Service) and the North Carolina Geologic and Economic Survey have made extensive studies concerning its habits and life history, and have carried out comprehensive researches extending over many years on methods of propagation. A large part of these studies were carried out at the Biological and Fish Cultural Station at Beaufort, North Carolina.

Although at low tide terrapins are usually found nearly or entirely buried in the mud or hidden under drift, some may be occasionally seen crawling about. At high tide they swim over the marshes in search of crabs, snails and other gastropods, and marine worms on which they feed. Terrapins grow rather slowly, requiring about 6 years to reach maturity; the female at that time is 5½ or 6 inches long and the male about 4 or 4½ inches long. In the spring or early summer the terrapins lay their eggs at a depth of 3 to 8 inches on sandy elevations in the marshes usually above the high-tide mark. The "nests" contain on the average of a dozen eggs each, but this amount may vary from 2 to 12. The eggs hatch about 3 months after they are laid; the newly hatched terrapins seldom eat any food before they hibernate, but live during the winter on the masses of egg yolk in their stomachs.

Many individuals have attempted to raise terrapins, but without much success. It required a thorough study of the problem for the Fisheries' investigators to discover the cause of the failures. These investigators succeeded by studying the terrapins in their native abode and then by keeping them under conditions similar to those to which they were accustomed.

The terrapins are impounded on a well-protected gently sloping shore of sand or clayey sand, so situated that at high tide every part of the enclosure, with the exception of the egg beds, is covered with water, and at low tide half the area is still covered. The enclosed area should allow at least 10 square feet for each impounded adult terrapin. The walls of the pen must be high enough and strong enough to overtop the highest tides by at least 3 feet and to resist any waves which may strike them. The pen is divided into two parts—a large area for the adult terrapins and a much smaller one for the young. The enclosure for the young

should be partly dry at low tide, but should always contain some water. Young terrapins are good climbers until they are 2 or 3 years old; therefore their pen must be constructed with great care. The adult terrapins are fed on fish and crabs; the young terrapins are usually given fish or oysters during their first winter. Terrapins can thrive without fresh water, but their pens are usually supplied with fresh water in a shallow drinking trough.

A bed of sand above the highest tides is provided as a nesting place. After the close of the laying season the adult terrapins are kept off the egg bed. Usually about 90 per cent of the eggs hatch. As the eggs hatch, the young terrapins are collected and placed in the shade in tubs or tanks containing a little fresh or salt water. Feeding with fish, crab meat, or oysters is commenced as soon as the young terrapins are placed in the tanks; at first only a few eat, but after 3 or 4 days most of them begin to feed. If young terrapins are allowed to hibernate, suitable quarters should be prepared for them as soon as cool weather comes. A large box containing layers of sand and eelgrass when sunk in the sand in a well-drained spot serves the purpose. It has been found that it pays to keep the newly hatched terrapins in a warm house during their first winter, thus preventing their hibernation. By this means the terrapins are fed through the winter, and none is lost because of hibernation. The winter house is constructed like a greenhouse, with the south slope of the roof of glass, and is heated by a coal stove which maintains the temperature between 80 and 85° F. The tanks are placed on trestles in this house, and the terrapins are fed as before.

The young terrapins should be kept separate from the older ones until they are 3 years old. The older terrapins do not harm the younger ones intentionally, but in a crowded pen they kill their offspring by trampling them and depriving them of food.

The Fish and Wildlife Service has been very successful in propagating terrapins at the Beaufort Station by the method just outlined. The experiments have dealt with only 2 species of the diamondback terrapin, namely, the Carolina terrapin and the Texas terrapin; however, it is probable that the other 3 species may be successfully propagated by similar methods.

There are a number of commercial hatcheries in operation in the Chesapeake Bay area at the present time.

Methods of Fishing. Because of the scarcity of terrapins the fishery is of little importance commercially, and only a relatively few fishermen engage in it as a part-time occupation. The dragnet and the dip net are 2 common instruments of capture. With the former, the net is set across the lower part of the marsh creek or river while the fishermen rout the terrapins out of the upper part of the river; the terrapins driven out in this manner go downstream with the tide and are caught in the net.

At high tide, when the terrapins are swimming about and feeding over the marshes, they are sometimes taken in dip nets. The fisherman poles his skiff among the grassy areas and watches closely for terrapins which are found feeding on the small snails which live on the marsh grass. When a terrapin is seen, it is captured in the dip net or crab net.

A more common method of fishing is followed at low tide by men who, while wading in mud, carry a stick with which they probe into the soft mud in their search for terrapins which lie nearly buried.

Marketing. Most of the larger terrapin are shipped to Baltimore, New York, Philadelphia, and other large cities. "Chesapeakes," procured from Chesapeake Bay, average nearly 6 pounds each and command the highest prices; while those from the North Carolina region bring slightly less. The terrapins from Georgia, Florida, and Alabama are much smaller than either the North Carolina or the Chesapeake species, and average only about 3 pounds each; consequently, they sell at a much lower price.

At one time small quantities of terrapin were canned in Georgia, but their rapid rise in price has placed their cost beyond the reach of the canner.

Snapping Turtles

Although the snapping turtle is not generally considered a marine product, there is some market for it. Two species of this turtle are commonly marketed, particularly in the mid-western states; these are the common snapper (*Chelydra serpentina*) and the hardshell or alligator (*Macrochelys lacertina*). Some individuals of these species reach a weight of 35 to 40 pounds, but are ordinarily much smaller than this. They are incidentally caught with many types of gear by the fresh-water fishermen. They can be caught with almost any type of gear in the lakes and streams.

Some of the meat is canned and some made into snapper soup. In general these operations are similar to those employed in the sea-turtle industry. The statistics of the catch are reported in Table 146 (p. 657).

The Frog-Leg Industry

Several edible species of frogs are found in the markets. The common bullfrog (*Rana catesbeniana*) is the largest and most often used. Some of the others are the green frog (*R. clamitans*), the southern bull frog (*R. grylio*), the leopard frog (*R. pipiens*), the southern leopard frog (*R. sphenocephala*), the pickerely frog (*R. palustris*), etc.

Frogs are found in low swampy areas. Their food consists of insects, small fish, and crayfish. The larger ones have been known to swallow a 3-inch fish or young turtle. Since the frogs bury themselves in the mud and hibernate in cold weather, fishing is carried on only during the warm months.

Fishing for frogs is usually most successful at night, with the aid of strong lights along the shore. They may be caught with hooks attached to a line on a pole and baited with a piece of bacon rind or the like; or, they may be simply "hooked" under the chin without the use of bait. Many are caught with a dip net or in traps; some are shot with a small-caliber rifle.

Usually the back or jumping legs are the only part of the frog eaten. They are dressed for market by being skinned; the two large legs remain attached by a small portion of the body meat. The legs are packed in barrels or boxes and well iced.

Louisiana and Florida are the chief points of production in the United States. Cuba exports considerable quantities to this country. Of late years they have been frozen successfully and shipped to market. When frozen they are packed in 1- to 5-pound cartons and glazed with a coat of ice or wrapped in some type of protective paper.

In 1948 766,262 pounds of frog legs, valued at $637,856, were imported into the United States. The greater portion of these came from Cuba.

REFERENCES

Anon., "Frog Culture and the Frog Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **102** (1944).

Anderson, A. W., and Power, E. A., "Fishery Statistics of the United States, 1945," U. S. Fish and Wildlife Service, *Statistical Digest,* **18** (1949).

Babcock, H. L., "The Sea Turtles of the Bermuda Islands with a Survey of the Present State of the Turtle Fishing Industry," *Proc. Zool. Soc. London. Series A,* **107,** Pt. 4 (1938).

Hildebrand, S. F., and Prytherch, H. F., "Diamondback Terrapin Culture," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **216** (1947).

Lagler, K. F., "Turtle: An Unrationed Ration," *Michigan Conservation,* **12,** No. 3, 6, 7 (1943).

McCutcheon, F. H., "The Respiratory Mechanism in Turtles," *Physiol.,* **14,** 3, 255–269 (1943).

Martinez, J. L., "Cuban Frog Leg Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **284** (1948).

Schmidt, K. P., "Turtles Collected by the Smithsonian Biological Survey of the Panama Canal Zone," Smithsonian Misc. Collections, **106,** 8 (1946).

Townsend, C. H., "Growth and Age in the Giant Tortoise of the Galapagos," *Zoologica,* **9,** 13 (1931).

CHAPTER 32

Miscellaneous Shellfish Industries of the United States

Scallops

The beauty of the scallop shell attracted attention long before the food value of this shellfish was recognized. In ancient times the savages used scallop shells for many decorative purposes. The first use to which the colonists put the scallop was as fertilizer. After severe storms, when these shellfish were washed ashore in large quantities, the New England farmers gathered them and spread them on their land. Later scallops were used as a stock feed. About 1870 the edible qualities of this mollusk became known and an important industry gradually developed. At present the scallop is classed as a delicacy. The fishery has been prosecuted so vigorously that the natural supply is rapidly diminishing. The price of scallops, while it has varied from year to year depending on the catch, has steadily increased; whereas the annual catch has remained the same or declined slightly.

The present industry is located principally in Massachusetts and New York although small quantities of scallops are also produced in Maine, Rhode Island, Connecticut, New Jersey, North Carolina, and other states along the Atlantic Coast. Small scallops are found from Cape Cod to the Gulf of Mexico. The giant scallop is found from New Jersey to Labrador, but is most abundant along the Maine coast. At one time it was a formidable rival of the shallow-water scallop, but in recent years the bay-scallop industry has declined until now relatively few are taken.

The latest available data relative to the production of scallops in the various states are presented in Table 147.

TABLE 147. SUMMARY OF THE SCALLOP CATCH, 1945.

State	Bay		Sea	
	Pounds	Value	Pounds	Value
Maine	—	—	71,400	$ 27,665
Massachusetts	423,200	$209,706	3,920,200	1,288,698
Rhode Island	427,800	198,510	—	—
Connecticut	7,300	4,195	2,600	870
New York	50,100	40,100	1,648,100	549,375
New Jersey	—	—	68,500	20,607
Total	918,400	$872,411	6,710,400	$1,387,215

Source: U. S. Fish and Wildlife Service.

Species of Commercial Importance. The scallop is a mollusk belonging to the *Lamellibranchia*. The family of *Pectenidae* includes about 40 species, 4 of which are found on the Atlantic Coast. Of these only 2 are of commercial importance.

The common shallow-water scallop, found from Massachusetts to the Gulf of Mexico, is the most important commercial species. This scallop is ordinarily designated as *Pecten gibbus,* var. *borealis* (Say) although it is also called *Pecten irradians.* In England it is called "fan shells," "frills," "queens," and "squims." The giant deep-water scallop, found from New Jersey to Labrador, is *Placopecten grandis* (Solander).

Several species of scallops are found on the Pacific Coast, but the western scallops are not utilized commercially to any considerable extent.

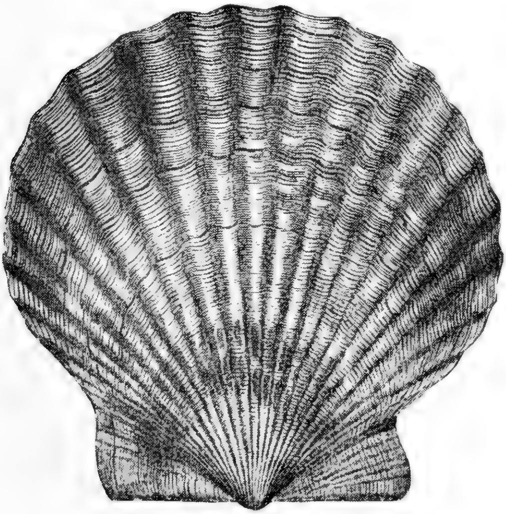


FIG. 32–1. The bay scallop (*Pecten irradians*).

(Courtesy U. S. Fish and Wildlife Service)

Placopecten grandis has a bathymetrical range from 1 to 150 fathoms. Because of the depth at which this shellfish lives, comparatively little is known about its habits. It possesses a much larger, smoother shell than *Pecten gibbus* and is, therefore, called "giant scallop" or "smooth scallop." It is also called, from the habitat, "sea scallop." The foot is relatively small, and is split at the end; it possesses a large byssal gland. The sexes are separate. The embryos pass through a free-swimming stage, after which they settle to the bottom and attach themselves to some object by means of a byssal thread in much the same manner as do the embryonic *Pecten gibbus.* The average length has not been determined; but this scallop, like the shallow-water scallop, seldom lives over 2 years.

Until recently comparatively little was known about the life history of this scallop. Unlike the giant scallop in which the sexes are separate, *Pecten gibbus* is hermaphroditic. The spermatozoa and ova are usually discharged alternately so that there is little danger of self-fertilization. Fifteen to 20 hours after fertilization the eggs become a swimming embryo. The movements of its cilia keep it from sinking to the bottom and cause it to rotate rapidly. A thin transparent shell secreted by the shell gland grows over the young scallop before it is 40 hours old. The young scallop does not take on the characteristics of the adult until 5 or 6 days after it has reached the veliger (swimming) state. During the last 3 days of the swimming state a foot, which aids in swimming, begins to develop on the

underside of the body. After its free-swimming existence the young scallop excretes a gelatinous substance which immediately hardens in the water and enables the scallop to attach itself by means of a byssus. As the scallop grows older, the foot gradually becomes smaller in proportion to the size of the shell. The mollusk takes on the characteristics of the adult, and begins to swim by opening and closing its shell. Scallops grow rapidly and are short-lived; only a few live 2 years. Scallops spawn when they are a year old, but few spawn more than once during their life.

Because of limited space a detailed description of the anatomy of the scallop cannot be given. This subject is considered in detail in Belding's report (1910).

Chemical Composition of Scallops. Analyses have been made of nearly all of the species of shellfish commonly eaten in America. According to the figures given in Table 148 scallops are higher in protein than any of the other common edible

TABLE 148. COMPOSITION OF SCALLOPS.

	Water	Protein N × 6.25	Fat	Total carbo-hydrates	Ash	Fuel Value
	%	%	%	%	%	Per lb
Minimum	77.8	14.5	—	1.1	1.3	305
Maximum	82.8	15.1	0.3	5.6	1.5	385
Average	80.3	14.8	0.1	3.4	1.4	345

Source: Atwater, W. O., and Bryant, A. P., "The Chemical Composition of American Food Materials," U. S. Dept. Agr., *Office Expt. Sta. Bull.*, **28,** *Revised* (1906).

shellfish. However, it must be remembered that only the adductor muscle of the scallop is eaten, whereas practically all the flesh of other shellfish is eaten.

Researchers have hydrolyzed the edible portion of the scallop and determined the amino acids resulting as cleavage products; their results are presented in Table 149.

TABLE 149. AMINO ACIDS OBTAINED FROM THE PROTEINS OF SCALLOPS.

	%
Glycocoll	0.00
Leucine	8.78
Proline	2.28
Phenylalanine	4.90
Aspartic acid	4.37
Glutamic acid	14.88
Tyrosine	1.95
Arginine	7.38
Histidine	2.02
Lysine	5.77
Ammonia	1.08
Tryptophan	Present
	52.51

The Scallop Fishery. The scallop fishery is a seasonal industry since most states enforce a closed season. In Massachusetts the closed season extends from April first

to October first. Legal restriction of the fishing was introduced in Massachusetts in 1885 in an effort to stop the rapid decline of the fishery. The closed season allows the yearling scallops time enough to spawn. Inasmuch as only a comparatively few scallops live to spawn the second season, if the small "seed" scallops are not disturbed, there is no danger of overfishing. Massachusetts now prohibits the taking of the young "seed" scallops.

Bay scallops are sometimes taken by an instrument called a "pusher." This consists of a wooden pole from 8 to 9 feet long attached to a rectangular 3- by 1.5-foot iron frame upon which is fitted a netting bag about 3 feet in depth. The fisherman, wading on the flats at low tide, shoves the pusher among the eelgrass and thus captures the scallops. When a bag-full is obtained, its contents are emptied into a dory and the fishing is continued. Obviously, this method is applicable only to shallow flats and can only be worked at low tide; it is not very profitable and is being discarded for more rapid dredging methods.

Scallops are mainly taken in dredges dragged along the bottom by catboats (sailboats) or powerboats (gasoline boats). The common form of dredge used in Massachusetts consists of an iron framework about 3 by 1½ feet, with a netting bag attached which will hold from 1 to 2 bushels of scallops. A single catboat or powerboat is used to pull from 6 to 10 dredges across the scallop grounds. When the dredges are hauled in, their contents are emptied on a culling board projecting slightly on both sides. The scallops are culled or separated from the rubbish while the dredges are pulled back over the grounds. The culled scallops are first put into buckets and later transferred to bags or dumped into the cockpit of the boat. Two men are usually employed on the larger catboats and powerboats although 1 man sometimes does the work. Several styles of dredges are in common use. The scraper is one of the most popular; it consists of a rigid triangular iron frame which has a curve of nearly 90 degrees at the base. A raised crossbar connects the two arms. A strip of iron, about 2 inches wide and set at an angle for digging in the sand, extends across the bottom and acts as a scraping blade. The top of the net is fastened to the crossbar and the lower part to the blade. The usual dimensions of this dredge are: arms, 2.5 feet; upper crossbar, 2 feet; and blade, 2.5 feet. The wooden bar keeps the net from catching on the bottom. Usually the lower part of the net consists of interwoven iron rings.

The catch is ordinarily taken to the fisherman's shed or shanty where the scallops are opened and the "eyes" removed. The adductor muscle, or "eye," is the only part of the scallop which is eaten. The remainder is edible and has an agreeable flavor; but, since prejudice rules that it is unfit for human consumption, it is used instead for bait or fertilizer. An expert scallop opener can open 15 bushels of scallops in a day; this is the equivalent of 9 to 11 gallons of scallop "eyes," as a bushel of scallops yields from 2.5 to 3 quarts.

Scallops are nearly always soaked in water before they are marketed; this makes the eyes swell and become plump, thereby causing about a 40 per cent increase in volume. This plumping process makes scallops very difficult to preserve; and since plumped scallops spoil very easily, it prevents their shipment to distant markets. Yet, because nearly all consumers demand the large plump "eyes," the practice will probably be continued indefinitely. The scallops are sometimes swelled by placing about 4.5 gallons of "eyes" in a 7-gallon keg and filling it with fresh water; after standing overnight more water is added and the scallops are

shipped to market. Upon arrival at the market, the scallops have increased to the full amount of 7 gallons. Other fishermen place the scallops in shallow trays, cover them with water, and allow them to stand overnight; the following morning the plumped scallops are placed in tubs or kegs and shipped to market. Boston and New York are the most important markets for scallops. Because of the limited time which plumped scallops may be kept fresh, few are shipped to inland cities.

The Giant- or Sea-Scallop Industry. Although giant scallops were taken in limited quantities along the coast of Maine, the fishery was commercially insignificant until 1883, when several large beds were discovered. Most of these beds have long since been exhausted. Many other beds have been located, but the fishery has been unable to supply the demand, and in recent years the quantity of these scallops taken in Maine has not exceeded 100,000 pounds of "eyes."

Because of the depth at which the giant scallops are found, they are taken chiefly with dredges which resemble those used in the shallow-water scallop fishery. These dredges consist of a framework of flat iron bars to which is attached a bag or pocket which holds the scallops scraped up by the frame. The underside of the pocket is constructed of interjoined iron rings; the top and sides are made of twine netting. The pocket is usually about 4 feet long, and its width corresponds with that of the framework (3 to 4 feet). The rope attached to the "pull-bail" of the framework varies in length from 50 to 150 fathoms, depending upon the depth at which the dredging is effected. Owing to the oblique position which it occupies when in the water, it is much longer than the perpendicular distance from the boat to the bottom. Several dredges are dragged along the bottom by a catboat or powerboat. In certain localities dredging is carried out by men in rowboats.

Recently a giant scallop fishery has developed along the Long Island Coast, near the mouth of the Sound, off the coast of New Jersey near Asbury Park, and along the coast of North Carolina. These beds are being rapidly depleted, for, in addition to dredges similar to those described above, large trawl nets are being used. Just how long these new fisheries will be profitable cannot be determined; as the beds are widely scattered, new beds continue to be discovered.

The catch is usually taken to the fisherman's shed where the shellfish are opened and the adductor muscle or "eyes" cut out. One and a half bushels of scallops are required, on an average, to furnish a gallon of meats weighing about 10 pounds. The giant scallop "eyes" are seldom plumped by soaking as are the shallow-water scallops.

Portland, New York, and Boston are the best markets for giant scallops. Smaller amounts are sold in Bangor, Augusta, and Belfast, Maine.

Freezing Scallops. On December 1, 1949 there were more than 2¼ million pounds of frozen scallops stored in refrigerated warehouses. Several types of packages are used. Although the 5- or 10-pound paper carton is the most common wholesale package, the telescope-top 1-gallon can is used by many of the packers. The paper carton has either a liner of moistureproof material or an overwrap of a type which will reduce deterioration.

Frozen scallops can be found in all stores handling family-size packages. These packages are usually the 12- to 14-ounce size, and the method of packing resembles that of the larger size described above. During the past few years this type of package has helped to increase the market.

(*Courtesy of Atlantic Coast Fisheries Co.*)

FIG. 32–2. Moisture-proof cellophane wrapped scallops packaged in telescoping waxed cartons.

By-products. Less than 10 per cent of the whole scallop is eaten; the remainder is used in a variety of ways. The waste organic tissue makes an excellent fish bait, and considerable quantities of this material are preserved by salting. Some of the refuse is used for fertilizer. The shells are often used in the construction of roads. Various dealers in novelties use relatively large quantities of these shells in the manufacture of souvenirs and other ornaments. The lower valve or shell is the only part suitable for ornamental purposes as it is the brightest and most beautiful.

The California Abalone Industry

Development of the Industry. For many centuries abalones have been highly prized by the orientals, particularly the Chinese; but only in recent years have they become recognized by Americans as an article of food. The Chinese preserve abalones by drying or by drying and smoking. As the interior of the abalone shell is very brilliantly colored mother-of-pearl (Chapter 8), the shells are valuable for ornamental purposes. The American Indians utilized the shells largely as ornaments and money. In Europe and in the Orient the shells are extensively employed in the making of inlaid work.

The early Chinese immigrants recognized that the California abalones were as valuable for food as the oriental *Haliotis* and began to gather these mollusks for their meat, which they dried and smoked and exported to China and Hawaii. Soon the Americans began to gather up the shells which the Chinese discarded; these were polished and made into various ornaments. As early as 1879 an important industry had sprung up; in that year over $127,000 worth of abalones were taken. The production of abalone in California in 1945 was 372,700 pounds, valued at $210,264. While this mollusk is found all along the Pacific Coast from California to Alaska, fishing is almost entirely confined to the coast south of Monterey Bay, California.

Physiology and Habits. The abalone, also called "sea-ear" and "ear shell," belongs to a family of marine snails, the *Haliotidae,* of which 6 species and 1 variety have been found on the Pacific Coast, but none on the Atlantic Coast. These large mollusks have well-developed heads. Each abalone has a powerful, adhesive,

creeping foot. Numerous contractile tentacles arise from the fringed epipodial fold around the base of the foot. The gills, alimentary system, kidneys, heart, and blood vessels lie to the left of and behind the columellar muscle and foot.

Some abalones are taken in shallow water at low tide, but they are more plentiful in water of 3 to 11 fathoms. The mollusks creep about on the bottom as they feed on kelp and other seaweeds. If a chisel is slipped quickly under the abalone, it is easily detached; if, however, the diver hesitates and the mollusk contracts its muscular foot, a powerful pressure is exerted and it is exceedingly difficult to pry the shellfish loose.

Fishing. The Japanese were the most expert abalone fishermen. Wearing diving suits, they went down into deep water and detached the abalones from the rocks by slipping a steel chisel under the expanded foot of the shellfish. The diver then put his catch into a basket let down from the boat from which he fished. When the net or basket had been filled with the shellfish, the diver gave the signal and the abalones were hoisted aboard. The basket was again lowered and the fishing continued. Each diver worked about 3 hours at a shift.

Some expert swimmers work without diving suits in water up to 20 feet in depth. They wear glasses to protect their eyes and put cotton in their ears. These divers are able to stay under water from 1 to 2 minutes and, when fishing on good grounds, bring up an armful of abalones each time.

American fishermen usually row near the rocks in relatively shallow water and examine the sea-bottom through an instrument, consisting of a short wooden box with a pane of glass in the bottom. This device permits an examination of the sea-bottom without disturbance by surface ripples. When an abalone is found, it is pried off the rocks by means of a chisel fastened to a long pole and raised to the surface.

A few Chinese fishermen wade in shallow water at low tide and collect in a basket any abalones that they may find.

Utilization. *Fresh.* Although properly cooked abalone is one of the most delectable shellfish, few Americans have acquired a taste for it. It is prepared for cooking by being cut from the shell; the visceral mass and mantle fringe are trimmed from the large central muscle, which is then cut transversely into slices. These small steaks may be fried, stewed, or minced and made into chowder. The juice makes an excellent bouillon.

The laws governing the local abalone fishery in California are very strict; it is not permissible to take out of the state those locally caught. The season is closed to fishing from January 15 to March 15. Commercial operations dealing with imported abalone require an import license, and the sizes are prescribed. Drying and canning the native stock is prohibited; however, considerable quantities of this shellfish are imported from Mexico, and it is permissible to dry and can those imported.

Dried and Smoked. The dried abalones are prepared chiefly by the Chinese and Japanese inhabitants of California. They remove the abalones from the shells and put them in brine for a few days. This operation removes the mantle fringe and aids in preserving the meat. After washing, the salted abalones are cooked for about half an hour in water just below the boiling point. The oriental workmen transfer the abalones to baskets and carry them to the drying frames where they are spread on shallow trays to dry in the sun. Four or 5 days later the abalones

are cooked again for an hour. After the second cooking the shellfish are smoked for a day with charcoal smoke. They are rinsed in boiling water and finally dried for about 6 weeks; after rinsing in warm water the dried abalones are ready for use.

This drying process causes a loss in weight of approximately 90 per cent. The dried abalones are brown, hard, and tough, yet they can be sliced with a sharp knife. The Chinese stew this dried product after soaking or grind it into a powder and use the pulverized abalone for the preparation of soup.

Canning. After its removal from the shell the abalone is prepared by cutting away the visceral mass, washing, and then brining for about 48 hours. The black envelope around the foot is removed. For the American trade only the foot muscle is minced and prepared for canning, but, for the oriental trade both the foot muscle and the mantle are cut into cubes and canned.

The minced meat is packed into tin cans which are then exhausted for 45 minutes at a low temperature. The exhausted cans are sealed and sterilized in a retort under 15-pounds steam pressure for 1 hour. After cooking, the cans are cooled with a spray of cold water, labeled, and packed into cases.

By-products. The shell products can scarcely be considered as by-products as they are of much greater value than the preserved meat. Many important articles are manufactured from the mother-of-pearl with which the shells are lined, including the following: cuff buttons, knife handles, paper knives, inkstands, buttons, and many other useful ornamental articles. This industry is described in Chapter 8.

Glue has been prepared from the viscera.

Pearls and blister pearls are often found in abalones (Chapters 7 and 8).

Sea Mussels

Possibilities of the Industry. Sea mussels are widely distributed along the coast of North America, and are abundant on the Atlantic Coast from North Carolina northward and on the Pacific Coast from San Francisco to Alaska. They usually grow in large beds on the surface of mud or sand along the low-tide mark, and often extend to a level several feet below low-tide water; they are also found in deeper water up to 100 fathoms.

Curiously, while the oyster, clam, and scallop have been commercially exploited in America, the sea mussel, which is an important European shellfish, has been neglected. Although some are sold in the shell in New York, San Francisco, Seattle, and other important fish markets, they have never come into general use as a food. In 1945 only 45,773 standard cases of 48 pounds each were canned. A small quantity of mussels are preserved by pickling in vinegar. Mussels have a limited use as fertilizer, and some are used as fish bait. The latest available figures relative to the production of sea mussels by states are given in Table 150 (p. 674).

In Europe the demand for mussels for food and bait is so great that the natural supply is unable to meet it; therefore, much attention has been given to mussel culture. Great Britain, Ireland, Holland, and France consume large quantities of mussels annually. Thousands of "bouchots" or mussel hedges dot the French coast. French mussel culture dates back to the 13th century, when an Irishman named Walton is said to have originated the "bouchot" system; this has been successfully applied ever since. Walton observed that mussels grew larger and finer flavored on

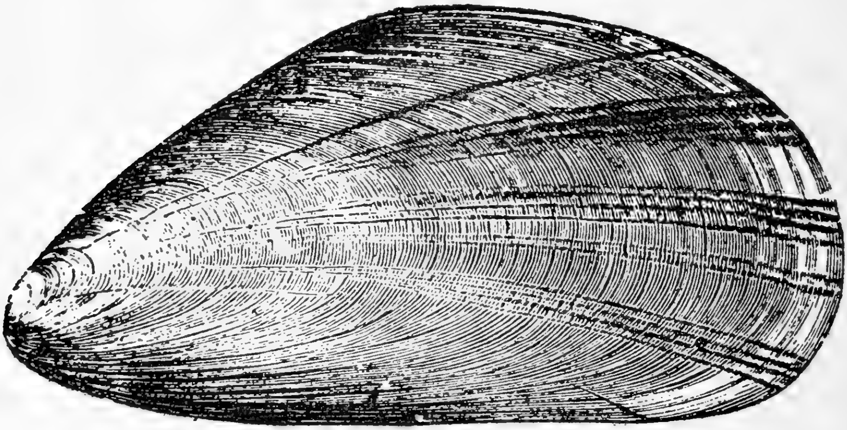
TABLE 150. PRODUCTION OF SEA MUSSELS BY STATES, 1945.

State	Pounds	Value
Maine	2,733,400	$72,146
Massachusetts	49,800	9,486
New York	429,600	86,696
New Jersey	3,600	450
Virginia	49,500	7,070
South Carolina	43,000	5,375
Total	3,308,900	$181,226

Source: U. S. Fish and Wildlife Service.

stakes than on the mud of the flats. He therefore constructed a double hedge of stakes along the low-tide mark which offered a large surface for the growth of mussels.

Species Utilized. Two important species of mussels are found on the North American Coast; *Mytilis edulis,* Linnaeus, occurs on the Atlantic Coast as far south as North Carolina, while this species and a closely related species, *Mytilis californianus,* Conrad, are found on the Pacific Coast from Alaska to San Francisco. The



(Courtesy U. S. Fish and Wildlife Service)

FIG. 32–3. The sea mussel (*Mytilis edulis*).

latter when full grown is much larger and has a rougher shell than *Mytilis edulis.*

The favorite habitat of these mussels is at the low-tide mark in slightly brackish water, along swift tide ways, and in protected bays and estuaries. Mussels often attach themselves to the piles and timbers of bridges, wharves, and to other objects, such as rocks and buoys.

The internal structure of mussels bears a general resemblance to that of the clam and many other bivalves. The mussel is characterized by the small, strong, triangular foot, and especially by the strong and prominent byssus or "beard." The byssus enables the mussel to attach itself firmly to the shell of another mussel, or to a rock or some other object. A viscous liquid is excreted by glands, which

are under and behind the foot, and solidifies as soon as it comes into contact with the water, thus forming a thread. A number of the threads form the "beard" which enables the mussel to anchor itself firmly. Many thousands of mussels are often seen thus attached to each other on acres of tidal flats at low tide. The foot of the mussel is a brown- or purple-colored muscular organ; its tip is able to exert suction by means of which the mussel is able to take firm hold of any hard object.

Mussels feed on diatoms and other microscopic forms, larvae, etc. They grow rather slowly, requiring from 1 to 8 years to reach maturity. In Europe seed mussels from 2 to 3 years old are often collected and planted until they reach marketable size; this requires from 2 to 5 years. The rate of growth depends upon the temperature, the amount of food, and the rate of movement of the water. The most rapid growth is usually obtained, other conditions being equal, in the bottom of the tidal streams where the mussels are never uncovered and where there is no deposition of silt. Under such conditions mussels occasionally reach a length of 3 inches in a single year.

Composition. The edible portion of mussels contains a relatively large amount of protein compared to oysters and clams. The edible portion of scallops contains a higher percentage of protein, and that of oysters contains more carbohydrates. But, since the mussel shells are thin and light, the proportion of refuse is much smaller and so the total amount of nutrients in a bushel of mussels is considerably greater than in the same quantity of any other common shellfish.

Field (1922) reported experiments by Alsberg and Clark and Bennett which indicate that sea mussels are about as easily digested as hard-boiled eggs and nearly as completely digested as raw beef. The composition of whole mussels and the edible portion of mussels is given in Table 151.

TABLE 151. COMPOSITION OF SEA MUSSELS.

	Refuse	Water	Protein $N \times 6.25$	Fat	Total Carbo-hydrates	Ash	Fuel Value per lb
	%	%	%	%	%	%	Cal.
Whole mussels [1]	46.71	44.9	4.6	0.6	2.2	1.0	150
Whole mussels [2]	46.69	41.1	5.0	0.8	0.85	—	140
Edible portion [1]	—	84.2	8.7	1.1	4.1	1.9	285
Edible portion [2]	—	83.27	10.18	1.64	1.74	1.99	299

Source: [1] Atwater, W. O., and Bryant, A. P., "The Chemical Composition of American Food Materials," U. S. Dept. Agr., *Office Expt. Sta. Bull.*, **28**, *Revised* (1906), and [2] Field, I. A., "Food Value of Sea Mussels," U. S. Bureau of Fisheries *Bull.*, **29**, 85–128 (1909).

Methods of Fishing. Mussels are very easily taken, in most cases, as they often lie attached to each other in huge beds in relatively shallow water. Dredges are ordinarily used in taking this shellfish and usually yield large returns for the amount of labor expended. Because of the danger of contamination with decomposition products mussels that are exposed at low tide are seldom taken for food.

In Europe rakes as well as dredges are used. Rakes are usually preferred as they do not crush the shells nor cause the sand to shift over the bed. The common

rake has a breadth of 18 inches, with teeth 1 inch apart, is attached to a pole 20 to 25 feet long, and has a wire net bag behind it for holding the catch.

Utilization. *Fresh.* Mussels spoil very quickly after they have been removed from the water. Shucked mussels cannot be kept fresh in an ice chest for longer than 24 hours, and cannot, therefore, be shipped long distances. This is the most serious drawback to the development of trade in fresh mussels. Mussels are ordinarily marketed alive in the shell, and are shipped in barrels like clams (i.e., covered with wet cloths and stored in cool dark places).

Mussels are best from December to July; they therefore may be used as a substitute for oysters during the early summer.

Mussels are eaten entire, except for the shell and the beard or byssus. The byssus is usually detached after cooking. Mussels may be stewed, steamed, roasted, fried, creamed, and made into croquettes, fritters, and chowder.

Pickled. Pickling is the most common way of preserving mussels. After washing, the mussels are steamed until the shells open. The meats are then taken from the shells and the beards are pulled off. The mussel meats are placed in a bowl and covered with spiced vinegar, onions, black pepper, red pepper, cloves, salt, allspice, olive oil, garlic, etc. When thus prepared and left in a cool place they will keep for a week or two. Pickled mussels are also prepared without steaming, but this process is not as common as the one described above.

Pickled mussels are also canned. The beards are pulled off after the mussels have been washed, steamed, and removed from the shell. The liquor formed during the steaming process is mixed with spiced vinegar. Field recommends that for each quart of natural liquor the following ingredients be added: 1 pint vinegar, ½ ounce cinnamon, ¼ ounce cloves, ¼ ounce salt, and 1 small red pepper. This mixture is allowed to simmer for 15 minutes and is then poured over the meats. After standing a day the meats are removed from the spiced liquor and are packed in bottles or jars. The liquor is filtered, heated to boiling, and poured over the meats in the jars. After sealing, the jars are heated for 15 minutes in an autoclave with 5-pounds steam pressure.

Canned. Field (1909) indicated that mussels could be successfully canned. The freshly gathered mussels were picked over carefully, and all of the dead or unhealthy ones, along with any other foreign material, were removed. They were then washed with clean water and steamed for 5 to 10 minutes, or until the shells opened slightly. As soon as they were sufficiently cool to be handled, the meats were separated from the shell and "beards" and packed into glass jars or tin cans.

The liquor from the steamed mussels was filtered through a muslin cloth to remove all shell particles or sand. It was then brought to a boil, and 2 ounces of salt per gallon of liquor were added. The hot liquor was added to the mussel containers, almost filling them. The containers were then sealed and processed in a retort at 5-pounds pressure for 15 minutes. In order not to cause excessive breakage of the glass containers the temperature was cooled slowly to about 100° F (38° C). When this temperature had been reached, the jars were ready to remove and store.

Jarvis (1943) describes a slightly different procedure for canning mussels. After they are thoroughly cleaned and culled, the meats are taken out of the shell. They are washed and brined for 1½ to 3 hours in a 3 per cent brine solution. The meats are then drained and placed in a 3 per cent solution of distilled vinegar to

which has been added from 1 to 3 per cent by weight of salt. The pickling in vinegar and salt is continued for about 3 days.

A spiced vinegar sauce is prepared from vinegar, bay leaves, white pepper, mustard seed, cloves, fennel, and paprika. The pickled mussels are drained and packed in 5- or 8-ounce glass jars, and the sauce is added. The glass jars are capped and processed for 25 to 30 minutes at 221° F (104.6° C), after which they are ready for marketing. The largest markets for these mussels are in Boston, Philadelphia, and New York.

Canned mussels possess an attractive appearance and pleasing taste. They do not shrivel when canned as do oysters, but remain tender and retain the full flavor.

The dehydration of mussels has been studied by Field (1909) and others, but has never been applied commercially.

Other Uses. In Europe large quantities of mussels are used as fish bait. Their use in America for this purpose is very limited. Mussels and mussel muds (mussel beds buried with silt) are used as fertilizer where they may be obtained easily in large quantities. Both mussels and mussel muds are used by the truck farmers along the coast in New Jersey and Long Island. Large quantities of mussel mud are used on Prince Edward Island, where extensive deposits, varying from 5 to 25 feet in depth, are found. The shells, usually more or less intact, are found embedded in dense deposits of silt. The mussel mud is obtained by means of dredging machines operated from rafts. It contains organic matter, lime, and small quantities of phosphates and potassium compounds, and is an excellent fertilizer for acid or exhausted soil.

A method of utilizing sea mussels has been developed in Denmark. The mussels are dried at a high temperature and then ground. The meal produced is considered an excellent feed for chickens. One sample contained the following constituents: calcium salts, 71.41 per cent; carbohydrates, 13.21 per cent; nitrogenous matter, 11.64 per cent; fat, 1.68 per cent; and water, 2.06 per cent. This material supplies the grit necessary for strengthening the egg shells as a considerable amount of nutritious feed is obtained from the dried mussels.

Other Shellfish Industries

Small quantities of many other marine mollusks are utilized commercially, including the following: natica, cockle, periwinkle, piddock, squid, donax, cephalopod, chiton, and conch.

Perhaps the most important of these mollusks is the squid, which is commonly used as bait by many of the trawl and hand-line fishermen of New England, Eastern Canada, and Newfoundland. This mollusk belongs to the devilfish family and is a favorite oriental marine delicacy. Squid is used to some extent as bait on the Atlantic Coast, but on the western coast it is marketed fresh, dried, and canned. During 1945 1,733,021 pounds of squid were frozen for storage. The common squid (*Loligo opalescens,* Barry) is eaten chiefly by the Chinese and Japanese inhabitants of the Western states and by the Italian and Spanish of New York and Boston.

In California squid are now taken usually in the large lampara nets used for sardines, and under similar conditions (i.e., at night). When a school is located, the net is thrown around them; they are drawn to the boat and the net is emptied the same as with sardines.

Squid is sold fresh in most of the important fish markets of California, Oregon, and Washington, and in New York City. Only one California cannery packed squid in 1921, but in Spain considerable quantities are canned in olive oil. The most important method of preservation is sun-drying, and considerable quantities of this mollusk are preserved in this manner in California for the oriental trade.

Coleman (1933) states that the methods of drying squid vary according to the quality of the product desired. The best quality of selected squid must be at least medium-large size (10 to 18 inches in length). They are split, and the pen and ink bag is removed; they are then scraped, spread out flat on the ground, and dried, with very little or no salt. They are frequently turned, generally by hand, and when thoroughly dried and hard are packed in barrels or boxes and shipped to market.

The cockle industry of Europe is one of the important shellfisheries of that continent, and is particularly important on the coasts of the British Isles; yet, in America this shellfish is almost neglected. The common cockle (*Cardium corbis*) flourishes along the northwestern coast from Coos Bay, Oregon, northward. Fresh cockles are eaten to a limited extent in Oregon, Washington, British Columbia, and Alaska. Some cockles are canned in the vicinity of Tillamook Bay and sold as clams.

Periwinkles and whelks are commonly eaten in Europe, but the American species are seldom utilized for any purpose. The most important Atlantic species (*Buccinum undatum*, Linn) is found from Cape Cod northward. This is common along the Alaskan Coast. The small periwinkle (*Littorina litorea*) is found in abundance on all our coasts. Both *Buccinum undatum*, the English whelk, and *Littorina litorea*, Linn, the English periwinkle, are taken in large quantities on the coasts of the British Isles.

The piddock is found in the United States along the eastern coast from Cape Hatteras southward, and is commonly eaten in the West Indies. This mollusk (*Pholas costata*) is larger than the European species (*Pholas dactylus*), which is utilized for food by the French, particularly those living along the coast of Normandy.

The moonshell, or natica, is one of the common shellfish on both the Atlantic and Pacific Coasts, where it occurs from New Jersey to Maine and from California to Alaska. Although this mollusk is excellent as food, little use has been made of it.

On the Florida and southern California coasts the donax (*Donax laevigata*, Deshayes) is found in considerable quantities. The shells are less than an inch long and appear short and stumpy, cut nearly off at one end and tapering to a rounded point at the other. This mollusk varies in color from white to pink and purple. These shellfish are used principally in soup, which is prepared by boiling the entire mollusks in a large pot of water. The soup is strained from the shells and is occasionally canned, but usually loses its delicate flavor during the canning process.

In Florida the donax is commonly called "coquina." It is captured by burying a box with a heavy screen bottom, called a "coquina scoop," in the sand at the edge of the tide line. As the tide breaks on the sand, the coquina are washed in and immediately burrow into the sand. After the box has been buried for an hour or two, it is dug up and dipped into water to wash out the sand. The coquina are trapped by the wire bottom. To hasten commercial operations the beach sand is

scooped up and put into the boxes and then the coquina are washed out. The production of coquina in 1945 was 54,000 pounds, valued at $13,500.

Along the coast of Florida there are considerable deposits of coquina shells which have become cemented together into a solid block of limestone. This coquina limestone is highly valued for decorative purposes. In many homes fireplaces and mantels are constructed of the stone. One reason for the value placed on the stone is due to the delicate colors which have remained in it.

There is a small trade in octopus on the Pacific Coast. The most abundant species is *Polypus hongkongensis;* small individuals of this mollusk are found in shoal water and much larger ones in deep water. Some are caught in the Puget Sound and along the California Coast. They are usually caught in traps resembling those used in the crab fishery, and sold chiefly to the orientals who make them into soup. Some are preserved by sun-drying without salt.

A number of species of chitons, none of which is utilized to any great extent, are found on the Pacific Coast. The black chiton (*Katherina tunicata,* Gray) is gathered and eaten by the natives of Alaska. The giant chiton (*Cryptochiton stelleri,* Middendorff) is found on the California Coast. Its chief use is in the making of curios, such as toy boats and electric-lamp shades.

REFERENCES

Ackerman, E. A., "New England's Fishing Industry," Chicago, University of Chicago Press, 1941.

Belding, D. L., "The Mollusk Fisheries of Massachusetts," *Mass. Fish and Game Commission Special Rept.* (1910).

Carson, R. L., "Food from the Sea: Fish and Shellfish of New England," U. S. Fish and Wildlife Service, *Conservation Bull.,* 33 (1943).

Coleman, R. A., "Methods of Preparation of Dried Squid for the Chinese Trade," U. S. Bureau of Fisheries *Memo.,* **S–240** (1923).

Field, I. A., "The Food Value of Sea Mussels," U. S. Bureau of Fisheries *Bull.,* **29,** 85–128 (1909).

Field, I. A., "Biology and Economic Value of the Sea Mussel (*Mytilus edulis*)," U. S. Bureau of Fisheries *Doc.,* **922** (1922).

Herrington, W. C., and Scattergood, L. W., "Sea Mussels," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **11** (1942).

Jarvis, N. D., "Principles and Methods in the Canning of Fishery Products," U. S. Fish and Wildlife Service, *Research Rept.* **7** (1943).

Loosanoff, V. L., and Engle, J. B., "Loss in Weight and Mortality of Sea Mussels in Storage at Different Temperatures," U. S. Fish and Wildlife Service, *Fishery Market News,* **5,** No. 4 (1943).

Medcoff, J. C., "Dark Meat and the Shell Disease of Scallops," Fisheries Research Board Canada, *Prog. Repts., Atlantic Coast Station,* **45,** 3–6 (1949).

Royce, W. F., "Gear Used in the Sea Scallop Fishery," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **225** (1947).

Walford, L. A., "Handbook of Common Commercial and Game Fishes of California," California Fish and Game, *Bureau of Commercial Fisheries Bull.,* **28** (1931).

CHAPTER 33

The Whaling Industry

Whales, Dolphins, and Porpoises

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History

The first great whaling nation of the world was England, closely followed by Holland. Both countries utilized the early techniques of the Basque whaler, who had been whaling on a small scale since about 1200 A.D. In the 17th and 18th centuries the English and Dutch caught right and bowhead whales successively from Spain to Spitzbergen to Greenland to Hudson Bay. Meanwhile, the Yankees of New England had started searching for right and bowhead whales, but they soon transferred their attention to the sperm whale which they pursued to all parts of the globe in competition with a few English boats. In 1846 746 whaling ships, with an aggregate capacity of 233,189 tons and a value of $21,075,000, were registered from American ports (mostly New England). The foreign fleet at this time numbered 230 vessels (Starbuck, 1878, and Scammon, 1874). With the growing scarcity of the sperm whale and the advent of petroleum the sperm and baleen whale fishery declined; but the fantastic price of baleen (whalebone) at $5.00 and even $7.00 a pound kept ships out after the few surviving right and bowhead whales. When the Norwegians began to utilize the powder harpoon-cannon and steamship and winch in the 1860's, whaling became an extremely efficient and profitable industry. The Norwegians have inherited the leadership in whaling from the Americans and Basques, and they now supply ships, gear, and men to the rest of the world. The English also have extensive whaling operations, and the Dutch and Russians have entered the field. The Japanese and Germans expanded their industries in the 1930's, and the former are still important whalers. The United States is scarcely to be considered a whaling nation, being represented by only one shore station on the West Coast, which operated from 1947 through 1949. Expensive labor, availability of cheap vegetable oils, and the lack of demand for whale meat tend to prevent any expansion of American whaling. However, for the past few years a large firm has chartered a British ship for sperm whaling off Peru and imported great quantities of sperm oil into the United States.

Classification of Cetacea

Whales, dolphins, and porpoises are members of an order of mammals, the Cetacea. They are not fish, though all are entirely aquatic and most are marine. Their capture for any commercial reason is called "whaling," or "whale fishery,"

"dolphin fishery," etc. Treatment or processing of the carcass yields many products: unmodified, primary, or raw products, and derived, processed, or secondary products. Further refinement to obtain other products is not considered a part of the whaling industry.

TABLE 152. WORLD WHALING STATISTICS.

Year	Total Whales	Total Whale and Sperm Oil Bbls.	Total Sperm Oil Bbls.	Total Shore Stations	Total Factory Ships	Antarctic Whale and Sperm Oil Bbls.
1933–34	32,586	2,588,335	?	15	23	2,395,544
1934–35	39,311	2,692,825	?	18	30	2,453,999
1935–36	44,868	2,873,423	161,959	37	33	2,436,338
1936–37	51,379	3,214,510	238,403	29	41	2,658,108
1937–38	54,835	3,640,248	134,896	35	35	3,340,330
1938–39	45,710	3,010,098	197,171	14	37	2,820,771
1939–40	37,631	2,666,522	155,228	7	29	2,544,253
1940–41	23,579	1,266,455	146,235	7	14	1,100,008
1941–42 *	6,870	201,570	85,332	7	2	77,819
1942–43 *	6,794	193,473	95,436	7	2	50,960
1943–44 *	3,965	197,058	30,999	7	1	132,001
1944–45 *	5,367	297,954	31,303	8	1	223,540
1945–46	19,335	948,411	66,257	31	11	818,652
1946–47	34,634	2,183,714	237,995	32	20	1,939,742
1947–48	41,989	2,394,087	305,744	39	20	2,104,051
1948–49	?	?	?	?	?	2,206,594

Source: (Up to 1946–47) International Whaling Statistics, **21**, Tables a, c, d and e (1949); 1947–48, *ibid.*, **23**, a, b, d, e (1950).

* These figures do not include the Japanese home islands and Bonin Islands for years 1942 through 1945, which, from Terry, W. M., "Japanese Whaling Industry Prior to 1946," Tables 9 and 11, Rept. 126, published by Nat. Res. Sect., Supreme Command for Allied Powers, Tokyo, 1950, are:

		Met. Tons	Met. Tons	
1942	1,168	1,841	1,145	19
1943	1,491	2,843	1,920	22
1944	2,169	4,281	3,211	28
1945	531	1,034	745	18

The yield in metric tons of oil was only a fraction of the total products, much of which was meat for local human consumption.

The following is a list of the *Cetacea* of the world. Whales are usually more than 20 feet long, dolphins are smaller than 15 or 20 feet and have a distinct beak on the head, and porpoises are similarly small in size but are without beak.

Class *Mammalia:* Mammals
Order *Cetacea:* Whales, dolphins, porpoises
Suborder *Odontoceti:* Toothed whales, dolphins, porpoises
Family *Platanistidae:* Long-beaked river dolphins

Platanista gangetica (the Gangetic dolphin, or "susu") is small in size. Although there is no large scale fishery, this dolphin is taken occasionally in the Ganges, Indus, and Brahmaputra rivers. Possibilities for extensive fishery are poor.

Inia geoffroyi (Amazon dolphin, "bouto") is also small. Though it has not been exploited, a limited fishery would be possible.

Lipotes vexillifer (White flag dolphin, Tung-ting dolphin) is a small species, restricted to Tung Ting Lake, Yangtze River, China. No fishery exists nor the possibility of one.

Stenodelphis blainvillei (La Plata dolphin, "tonino") is small and is not taken commercially, though a few are occasionally captured by fishermen off La Plata Delta, South America.

Family *Ziphiidae:* Beaked and bottlenose whales

Mesoplodon (a number of species). They are beaked and are from 15 to 20 feet long. None is fished regularly, though several species are occasionally taken (e.g., probably the *Mesoplodon bidens* of the North Atlantic). The Norwegians reported 6 beaked whales taken off W. Norway in 1929. Perhaps more were captured in the 19th century, when the fishery of the related bottlenose whales was more prevalent. Beaked whales usually have 1 or 2 pairs of teeth in the tip of the prolonged jaws. Their oil is largely a liquid wax with spermaceti present.

Ziphius cavirostris (beaked whale), though cosmopolitan, is not fished on account of rarity.

Hyperoodon ampullatus (flat-headed bottlenose, North Atlantic bottlenose whale) is found over the North Atlantic, with related forms in the southern oceans. The adult male has a large flat "boss" on the front of the head, and grows to around 30 feet. It was once fished extensively by the Scotch and Norwegians in the North Atlantic off Greenland, Iceland, the Faeroes, and Norway. The oil is waxy and is known as Arctic sperm oil, doegling oil, etc. The head fat also contains spermaceti.

Berardius bairdii (the giant bottlenose whale) grows to 40 feet, and is found in the Pacific. The only fisheries have been conducted by the Russians around the Okhotsk Sea and by the Japanese around Hokkaido and formerly also around the Kuriles. In 1948 the Japanese took 76 around Hokkaido. The oil is waxy and the head contains spermaceti.

Family *Physeteridae:* Sperm and pygmy sperm whales

Phyester catodon (sperm whale, sperm, cachalot) was made famous by the extensive literature concerning the famous sperm whalers, principally Yankees, of the 19th century and some of their famous opponents (i.e., Moby Dick, Paita Tom, etc.). In size the males reach 60 feet and the females 40. These whales are cosmopolitan and polygamous; harems of a few males and many females with young may be found in tropical waters throughout the year, and bachelor males occur in the colder waters of the northern and southern hemisphere in the summer.

The oil of the blubber and bone is largely a wax, that of the head, wax with much spermaceti, that of the meat half or more glyceridic, and that of the liver entirely glyceridic. The meat is usually considered unpalatable, but is eaten by the Japanese. The liver is low in oil, but high in vitamin A. Ambergris may be found in an occasional individual, usually an old male. The teeth are valuable for "ivory." The tendons sheathing the enormous fat organ or spermaceti organ of the head are not used, except in Japan.

The sperm whale is distinguished at sea by its long, low back with a slight

"hump" at one end and low spout thrown diagonally forward, as well as by its long series of 20 to 30 blows at surface for 5 minutes after a long dive of 30 to 50 minutes' duration. The bull sperm will sometimes give fight and damage a whaleboat or catcher boat. The carcass of this whale floats on the surface and is therefore easily handled.

The sperm-whaling grounds of today are the subantarctic where the factory ships take heavy toll of the bulls in a short period just before the opening of the season for baleen whales; the west coast of South America, where, since 1942, shore station and factory ship have operated among the breeding herds for short or extended periods at any season; the coast of Japan and the Bonin Islands, long-famous grounds which are capable of withstanding a yearly harvest of around 1000 sperm whales from both breeding and bachelor herds; the Azores, another famous ground, which produces by primitive methods of hand-whaling several hundreds of sperm whales from harem herds throughout the year; and South Africa, near Durban and Saldanha Bay.

In the 1945–46 season in the Antarctic and in 1946 elsewhere in the world 3418 sperm whales were taken, and in the 1946–47 season, 7395 (IWS, **21,** 8). Since then the annual world catch has probably remained high, perhaps around 8000. According to law, the minimum length permitted to be captured is 35 feet.

Kogia breviceps (pygmy sperm whale) is about 10 feet in length and is worldwide in distribution. It is solitary and rare and is never hunted.

Family *Monodontidae* (*Delphinapteridae*): Narwhal and beluga (white whale)

Delphinapterus leucas (white whale, white porpoise, beluga). The white porpoise inhabits the Arctic regions in large groups as an inshore species, and often ascends rivers. The adult attains a length of 10 to 16 feet.

The species is valuable for blubber oil, head and jaw oil, and hide-leather. The blubber produces a glyceridic oil valuable for illumination and as food. The glyceridic oil of the head and jaw is valuable as a lubricant for fine instruments due to its high isovaleric acid content. The liver is very low in oil, but has a considerable quantity of vitamin D. The meat is good for food.

The leather, however, is the most remarkable product. The outer layer of the dermis is particularly tough and compact and tans well; it is waterproof and has great tensile strength and elasticity due to the predominantly lengthwise fibers. It was formerly used extensively for boots, shoelaces, and belting as the "porpoise leather" of commerce. In 1900 approximately $200,000 worth of skins were on the market from a year's catch of about 7000 whales, of which 6000 came from Europe (Stevenson, 1904b).

Beluga fisheries have been economically important to the Eskimos in the Arctic, to the Norwegians in the North Atlantic and around Spitzbergen, to the Canadians on the Gulf of St. Lawrence, and to the Russians in the White, Kara, and Okhotsk seas. Today all these places, except Spitzbergen, are fished for white whale. A good catch is also obtained from the Greenland and Hudson Bay region. An American fishery in the Cook Inlet region in the 1930's was a failure (Vladykov, 1944).

Monodon monoceros (narwhal) is restricted to the farthest parts of the Arctic. The male is noted for its huge, twisted tusk, which is actually a projection of the left canine tooth. The only fishery of any importance is at Disko Bay, W. Green-

land, and Pond's Inlet, N. E. Baffin Island, where, in winter, numbers are occasionally trapped in small constricting leads by sudden prolonged freezes, and killed by the hundreds by the Eskimos.

Family *Delphinidae:* Dolphins and porpoises

Steno rostratus (long-beaked dolphin) is pelagic, and is found in all oceans. There is no fishery nor much possibility of one.

Sotalia (several species; delta dolphins). They are found in the fresh and brackish waters of the Orinoco and Amazon rivers, in the Indian Ocean, and the rivers of W. Africa. Although there is no fishery, possibilities of one may exist.

Prodelphinus (several species; spotted and bridled dolphins). They are somewhat pelagic, and are found in the warm waters of the Atlantic and Pacific. There is no fishery though possibilities may exist.

Delphinus delphis (common dolphin) is cosmopolitan, common in large or small groups, and both inshore and pelagic. It is fished extensively around Japan and the Black Sea; elsewhere (e.g., European coasts) it is taken casually in nets.

Grampus griseus (the grampus-porpoise). Although this species is a world-wide inhabitant which may be fished occasionally, it is of no real commercial importance. It may be referred to as the "cowfish" or "grampus" off the New England Coast, where it has been taken periodically for watch oil.

Tursiops truncatus (the bottlenose dolphin, Hatteras porpoise, etc.), like the common porpoise and blackfish, was economically one of the most important species of dolphin or porpoise in the United States. Throughout the 19th century and well into the 20th a fishery for the oil from the blubber and head existed at Cape Hatteras, and at times the leather and meat were utilized. At intervals another fishery was located at Cape May, New Jersey. The season was winter, from November to May, and large seines were used, being hauled by boats into position in front of an advancing school of bottlenose dolphins. No other extensive fishery of this species is known, but individuals were occasionally taken all over the world for meat and oil. The length is around 10 feet, and the distribution practically world-wide. This species migrates in large schools and frequents inshore waters. The yield from the average individual is about 2 gallons of blubber oil, and approximately half a pint of jaw oil, and a pint or so of head oil.

Lagenorhynchus (several species; striped dolphins) are found in northern seas. There is no fishery in the Atlantic, but the Japanese take a number of *L. obliquidens* yearly.

Cephalorhynchus (several species; banded and belted dolphins) are found in southern seas. No fishery exists and possibilities of such are unknown.

Orcinus orca (killer whale), a large porpoise, is world-wide in distribution, and is noted for its predatory habits on seals, other dolphins and porpoises, and occasionally larger whales. It is taken commercially in Japan, where 48 were captured in 1948.

Psoudorca crassidens (false-killer whale) is a large porpoise noted for its sporadic stranding in masses at various parts of the world. It is fished only off Japan, where the catch report is mixed with that of the pilot whale.

Orcaella brevirostris (Malayan shore porpoise) is a small species found along the coast or up the rivers of the Malay region. There is no real fishery, though some are taken by the natives.

Globicephala ventriculosa (the pilot whale, blackfish, caaing whale, etc.) is perhaps the most important species of small whale in the world. It strands in small herds or is driven ashore in even greater quantities off the Gulf of St. Lawrence, Cape Cod, Greenland, and especially Faeroes, where it is a major part of the local subsistence economy. It is practically cosmopolitan in distribution. The Japanese hunt it at sea. In the days of the pelagic sperm whaler blackfish were fished all over the world, especially in the mid-Atlantic. The oil then was mixed with that of the right whale though the head oil was saved for lubrication.

It is from 15 to 20 feet or more in length. In appearance it is pure black, with a white mid-ventral streak, heavy curved dorsal fin set forward of the middle, and a bulbous head. When enormous herds assemble on migration and move with semimilitary precision, such is the social cohesion that the whole group can sometimes be turned and driven onto the beach.

The average yield of body (blubber) oil is about 40 to 50 gallons, and from the head and jaw, about 2 gallons. Analysis of the head oil by distillation under reduced pressure, by Tsujimoto and Koyanagi (1937) showed a high content of isovaleric acid, of which some was waxy in the form of cetyl isovalerate. Toyama and Tsuchiya (1934) demonstrated the body blubber oil to be a normal glyceride with a low Reichert-Meissl value (low content of fatty acids of low molecular weight, such as isovaleric).

In the Cape Cod region blackfish beach themselves either accidentally or deliberately to escape the killer whales, and the carcasses are utilized. Today such a "fishery" yields most of the domestic United States production of natural watch and fine instrument oil.

When the summer migrating herds appear off Greenland, they are pursued and driven ashore. However, the catch is exceedingly variable; some years the whale does not appear at all, and in others hundreds are taken. This fishery has been prosecuted only since 1920, the supposition being that the gradually warming ocean currents off S. W. Greenland have brought the pilot whale farther north as they have the common porpoise and other marine animals (Anon., 1944).

In Japan the pilot whale, along with the minke whale, bottlenose, etc., is captured by the smaller whaling boats. The statistics are mixed with those of the false-killer whale, but it is believed that blackfish predominate in this category.

However, it is in the Faeroe, Orkney, and Shetland Islands, principally the former, that the pilot whale is annually taken in large numbers by drives on the beach, and enters importantly into the economy and culture of the inhabitants. This fishery has existed for many hundreds of years, and the annual toll for centuries probably exceeds a thousand (Williamson, 1945).

Lissodelphis borealis (finless dolphin) is distributed in northern seas, but fished only in Japan by the porpoise boats. Possibilities of a fishery elsewhere are not known. A southern species (*L. peroni*) is little known.

Family *Phocoenidae:* True porpoises

Phocoena phocoena (common porpoise, harbor porpoise, puffing pig, herring hog, etc.), with related geographic forms, is the common inshore and river porpoise of most of the world, especially the northern hemisphere. It is 4 to 6 feet long, weighs 100 to 200 pounds, and travels in small to fairly large groups. In the 19th century a fishery existed in the Bay of Fundy and Grand Manan Island,

where the Indians of the Passamaquoddy and Micmac tribes captured several thousand porpoises yearly and marketed the oil for lamps and lubricants; but with the advent of petroleum the industry gradually died out. A similar fishery was also carried on sporadically throughout the New England area (Ward, 1880; Gilpin, 1876; and Leighton, 1937). Today porpoises are captured for commercial purposes only in Greenland and Japan.

Neophocoena phocoenoides (finless porpoise) ranges from the Cape of Good Hope along the coast of the Indian Ocean, and thence up the Asiatic Coast to Japan; but it is fished only in Japan, where, however, the annual catch is not known.

Phocoenoides dalli and *truei* (white-bellied porpoises) are found in the North Pacific. *P. dalli* is the common porpoise of inshore waters of our northwest coast from California to the Aleutians and as far as Japan. It is not fished, except occasionally in Japan, though possibilities for a fishery exist elsewhere. It is about 5 feet in size and weighs 150 pounds. *P. truei* of Japan is captured regularly as a part of the porpoise and dolphin fishery.

Suborder *Mysticeti:* Baleen (whalebone) whales
Family *Balaenopteridae:* Finners, rorquals (grooved throats and dorsal fin)

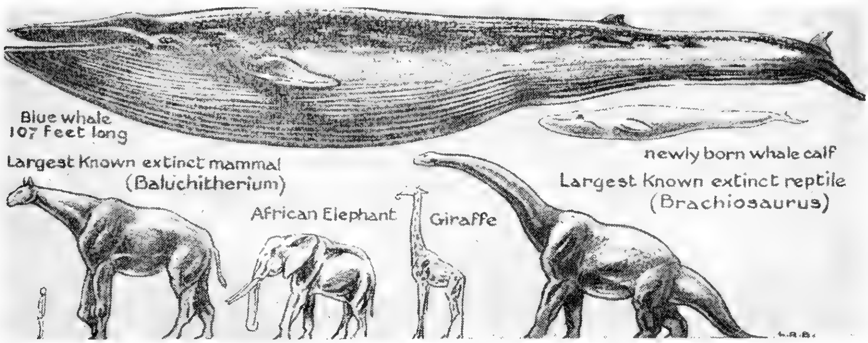
Balaenoptera acutorostrata (pygmy finner, least rorqual, sharp-headed finner, minke whale, etc.) is the smallest species of the well-known finners, the size rarely exceeding 30 feet. As a result it is not taken by the ordinary whaling industry; in fact it is whaled regularly only in Norway, Japan, and Newfoundland. The blubber is not thick, and consequently the main product is meat. The species is world-wide in distribution, and common in the Antarctic, where in time it may be taken by the southern nations which are able to completely utilize the carcass. The International Whaling Regulations do not require reports on the capture of this species. United States whaling regulations fix the legal minimum size length at 22 feet, but the industry has never reported any captures.

Balaenoptera borealis (the sei whale, pollock whale, etc.) is about 40 to 55 feet in size; but it is not a good oil yielder, and is taken mainly by the whale-meat eating nations, such as Norway and Japan. The sei whale is noted for the silkiness of the fringe of its baleen. International Whaling Regulations have fixed the minimum length as 40 feet; however, those of 35 feet can be taken for local human and animal consumption.

Balaenoptera brydei (Bryde's whale) is the size of the sei, but has some of the characteristics of the common finback. It is taken off South Africa and the Iberian peninsula at the shore stations. Elsewhere it has been recorded from the West Indies and Gulf of Guayaquil. It is not important. Regulations of the sei whale apply specifically also to Bryde's whale.

Balaenoptera physalus (common finback, finner, razorback, etc.) is the mainstay of the whaling industry today, even though it yields less oil than the humpback and blue whales, both of which it has replaced in the world's catch. From the Arctic to the Antarctic and from Norway to Japan the finback is the common whale of the industry. It will probably maintain this position on account of its hardiness as a species and versatility in its food and habitat. It ranges in size from 55 to 80 feet, the minimum legal limit being 55 feet; while 50 feet is the limit when the meat is to be used for human or animal consumption.

Balaenoptera musculus (the blue whale, giant finner, sulfur-bottom) is the largest whale; in fact, it is the most gigantic land or sea animal of all time. It can now mainly be found in diminishing numbers in the Antarctic, where it was once the backbone of the whaling industry. It attains a size of 100 feet, but averages between 80 and 85 feet and usually yields from 100 to 120 barrels of oil. The minimum size length is 70 feet, but it may be taken for meat when only 65 feet. The importance of the blue whale in the whaling industry in the northern hemi-



(*Courtesy American Museum of Natural History*)

FIG. 33–1. Scale drawing showing the blue whale as the biggest mammal there is or ever has been.

sphere is already a thing of the past, and its importance in the Antarctic is declining. Recovery of stocks and of usefulness to the industry cannot be expected until it is given a measure of protection as a species. Although the industry relies on the finback whale, it will take the blue whale whenever and wherever encountered.

Megaptera novaeangliae (humpback whale, nobhead, big flipper, etc.), one of our best-known species, is a rotund, long-flippered whale, having barnacles on head and flippers. It inhabits regularly visited, seasonal, feeding, breeding, or migration areas, generally inshore. Because it is a good oil producer and slow swimmer near the shore, it is the first to be affected by the opening or reopening of a whaling ground. Before turning to the finbacks and others, a company can rely on the local population of humpbacks carrying the operations for a number of years. It is not common now in the North Atlantic or in the Japanese area. It is somewhat commoner in the northeast Pacific; and, in the Antarctic and Australian seas it is returning to some of its former abundance after almost complete legal protection since 1938. The 1949–50 season in the Antarctic reopened the killing, and the over-all quota of 1,250 humpbacks were taken during the first two weeks. The International Whaling Regulations fix the minimum length at 35 feet, without exception.

Family *Rhachianectidae:* Gray whale

Rhachianectes glaucus (gray whale) is from 30 to 45 feet long, and was once the object of extensive whaling off the coast of Southern and Lower California and in Japanese inland waters. Although it was scarce at the turn of the century,

it built up its population to some extent and then suffered depletion once more in the early 20th century when it became necessary to protect it by international law. Now it is increasing again, and is confined in range to the coastal waters of the North Pacific, from Lower California to Alaska, and from Korea to the Arctic Ocean on the west.

Family *Balaenidae:* Bowheads and right whales

Neobalaena marginata (the pygmy right whale). This small and rare species of balaenid is found in Antarctic waters only, and forms no part of any whaling industry, past or present.

Balaena (or *Eubalaena*) *glacialis* and *australis* (the right whale of northern and southern waters) was once the famous whale of the industry. It was considered the "right" whale to take for its products of oil and long whalebone. So faithfully did the whalers follow this precept that the supply was soon exhausted. The history of the right whale is one of sad depletion of the European grounds, the North Atlantic grounds, the southern seas, and the Kodiak and Japanese grounds. Today the species receives complete protection under international law, and is beginning to be seen again in some of its former haunts. It attains 55 feet or more in length.

Balaena mysticetus (the bowhead, Arctic right whale, Greenland whale, etc.) is an Arctic cousin of the right whale, differing slightly in the greater size of the head, longer baleen, and some other details. Like the southern right whale it suffered the sledgehammer blows of the whaling industry; being in more restricted waters in summer and of more reduced general range it perhaps fared the worst. It is now also covered by international protection, and is increasing slowly in the Bering-Arctic and the Greenland-Canadian Arctic. Its maximum size is about 55 or 60 feet.

This brief survey of the *Cetacea* shows that formerly 4 species held the attention of the whalers of the world: right, bowhead, gray, and sperm. All but the gray were floaters, and could be taken with hand harpoon and line from the rowed whaleboat. The grays were taken close inshore where they could be recovered after sinking. Some humpbacks were also taken in similar fashion.

The smaller species, common porpoise, blackfish (pilot whale), bottlenose dolphin, common dolphin, white whale, narwhal, and bottlenose whale, were taken in varying numbers from place to place over the world. Today there is a fishery for all of the above, with the blackfish, white whale, and bottlenose whale taking the brunt of the effort.

From 1865 to 1920 the use of the harpoon cannon, steam whale-catcher, and later the whale factory ship enabled the whalers to fish for the finners and humpback. With the opening of the southern waters, particularly the pelagic Antarctic field, the harvest for these whalers has been fantastic; it is now tapering off somewhat, partially as a result of economic factors in the oil business and partially on account of the decline of whales. The sperm whale, after recovering well in the last 75 years, is again hunted intensively, especially in the grounds off western South America and in the sub-Antarctic. The industry is attempting to utilize more of the whale, but oil is still the most profitable product and reflects the success or failure of the operations. Meanwhile, meat, meat meal, bone meal, frozen glands, meat extract, liver oil, etc., are marketed along with the oil. The

modern industry first fished for the blue whale and humpback; when these declined, it shifted to finbacks and possibly the sei whale.

Modern Whaling

Method of Hunting and Equipment Used. The whale is hunted from a powerboat and shot with a harpoon attached to a line. After death it is hauled close, inflated, and eventually towed to the station or factory ship. The technique has been much the same for the past 75 years or more, except that the ships have become more powerful and the harpoon guns more accurate and long-ranged; also, the whale may now be run down instead of stalked. The explosive harpoon, fired from a muzzle-loading cannon, is still by far the most common type; but a breechloader has been recently perfected and applied, and even more recently the electric harpoon has made its appearance. An experimental compressed-air harpoon with a liquid CO_2 head has been tried without much success. At one time ships were 100 tons and were 250 horsepower steam-powered; now they are about 500 tons and have 1500 horsepower. Diesel has not yet replaced the steam engine although it has been successfully used to a limited extent. The line is rigged as usual to springs in the hold or at the base of the foremast; but the forerunners and lines may now be made of nylon, and the lines alone sometimes of wire cable. Formerly, all forerunners were of the finest Italian hemp.

Whale-spotting by airplane has been tried at intervals since the 1930's; but, though successful when the weather is clear, it is so difficult to apply economically that it has not been universally adopted. The foremost exponent of this method has been Grierson.

The use of ASDIC or supersonic underwater detection has also been tried quite extensively since the end of World War II; though the opinion as to its performance is mixed, the general consensus is favorable (Clarke, 1948). The opposition maintains that the running whale dodges too fast for the ASDIC beam and that a good gunner can guess the whale's future movements with comparable accuracy. Nevertheless, there is no doubt that for long-range pursuit with the modern power catcher ASDIC helps.

The standard harpoon gun is a heavy muzzle loader about 4 feet long, with a 3½-inch bore and mounted on 2 swivels so that it can be turned quickly in any direction by a long 2-hand "stock" handle with trigger attached. Recoil is taken up in the mount. Detonation is by a 32-caliber blank shell. The harpoon itself is about 5 feet long and has a pointed, screwed bomb-head set above the barbs. The shaft is either split for the ring or strap of the line, or eyed like a needle at the base and grooved bilaterally for the steel cable strap of the line. The latter type of harpoon is heavier, weighing nearly 165 pounds over-all. It rarely bends in the shank, and consequently needs no expert and expensive blacksmithing after ordinary use. An 8 to 12 ounce charge of coarse, slow-burning black powder is the propelling force behind a mass of closely wadded tow and a hard thick rubber wad, grooved on the edge at one place for passage of gas. The bomb holds about 8 ounces of fine, fast-burning black powder, detonated by a spring-, cap-, and powder-actuated fuse which explodes about 3 or 4 seconds after discharge from the gun. The barbs are tied to the shank, and the whole harpoon is held in the barrel by another bight secured to the sight. Both of these lines snap when the gun discharges or the barbs spread.

The smaller whales are shot with a "bottlenose gun" of 1½-inch bore, mounted and operated in the same manner as the larger model. The small dolphins and porpoises are hunted from a special boat with pulpit prow and shot with shotgun and buckshot. Before the carcass sinks, the stunned animal is harpooned by hand

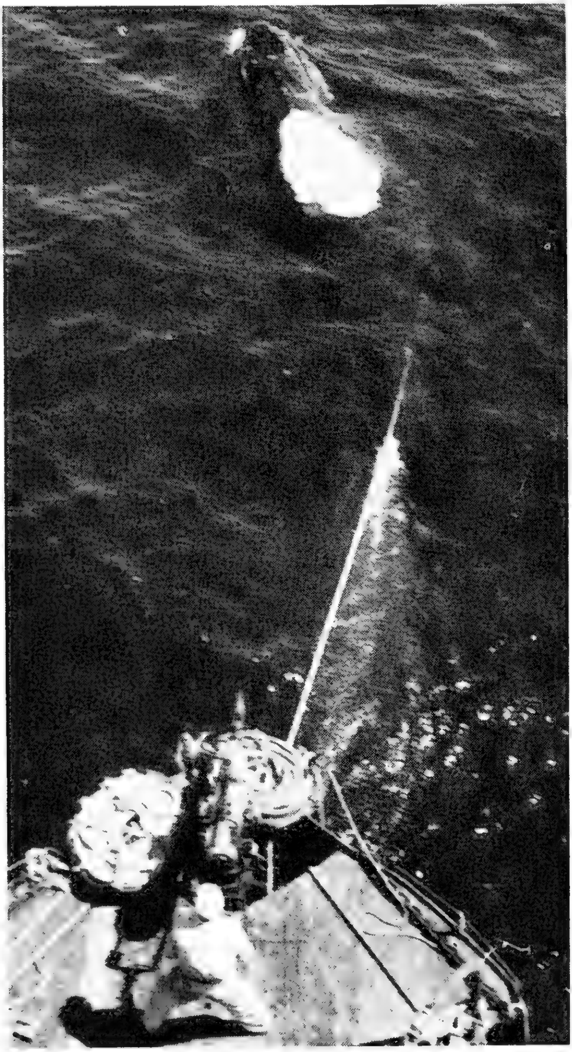


FIG. 33–2. A harpooned humpback whale in the western Australian waters.

(Courtesy U. S. Coast Guard)

and secured to a line tied to a small barrel which can be thrown over the side if there is no time to bring the carcass alongside and hoist it aboard.

Today most of the whales hunted, the rorquals or finners, sink when dead and must be inflated so as to be left floating while others are hunted, and to facilitate towing. Either the abdomen or the chest cavity and tongue are inflated, depending on which has not been perforated by the harpoon or fragments of the bomb.

Whales to be used for meat should be cut in the belly to cool the carcass, thus leaving only the chest and tongue for inflation. Exhaust fumes from a gasoline or Diesel motor may taint the flesh. The hole made by the inflating tube is well plugged to prevent loss of air and sinking, and a bamboo pole with a big red marker is planted on the carcass to aid in later detection. As wind and current drift a carcass remarkably fast and the modern hunt covers a wide area, many carcasses are lost after being inflated, flagged, and left. Foggy weather causes large losses. Probably the greatest loss of whales to the industry results from this practice; it may amount to 10 per cent. However, it is rarely figured in the annual catch. To prevent loss of marked drift whales a "whale transmitter," emitting at regular intervals radio signals of a certain wave length, is attached to the marker, and its signals are picked up by a direction finder.

Processing. The "small" or peduncle near the flukes is attached by a strap or chain to the bow of the whaleboat, and the dead whale is thus towed to the factory ship or shore station. Often the wings of the flukes are cut off to prevent dragging. A boat can tow up to 10 medium-sized whales, but rarely more than half a dozen large ones.

At the shore station the carcass is tied to a pile. It is then warped to the ramp and hauled to the flensing deck above the high-water mark by a powerful winch and cable attached to a strap around the base of the flukes, or "small." On a factory ship the strap of the tow is attached to a bight in a line running along the side of the ship. The line is hauled around the stern and up the ramp to bring the posterior part of the whale under the huge handlike Gjeldstad claw, which is dropped upon the lower back. The claw slides toward the flukes, closes like ice tongs, and locks at the "small."

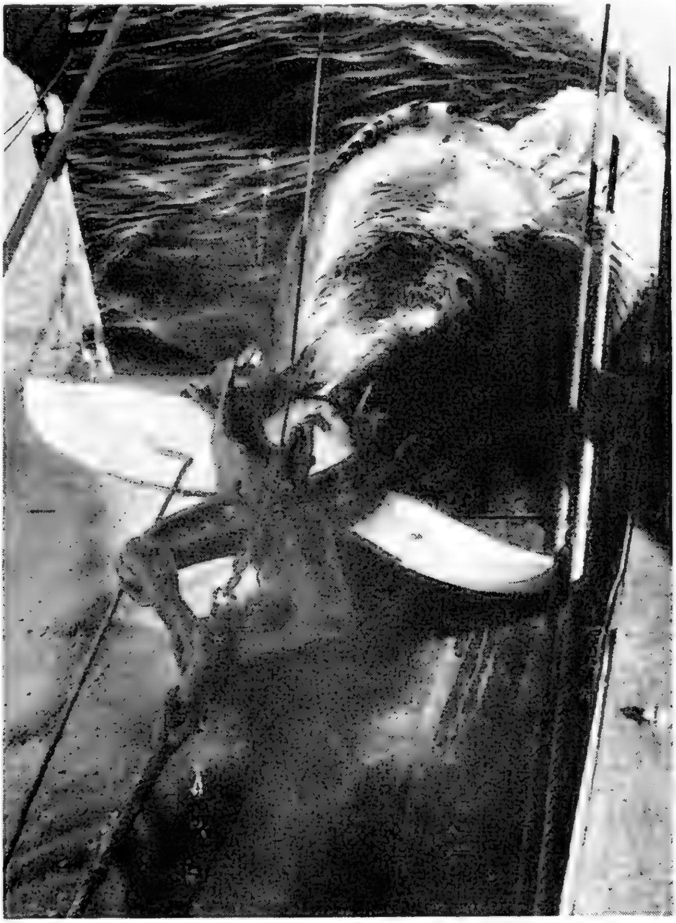
On the wooden flensing deck the carcass is stripped of its blubber in the same manner that a banana is peeled. The carcass is then rolled underside up and dismembered, the meat, glands, and bone being properly disposed of. The baleen is discarded. All work is done with cables and winches, and experienced winch men, cable tenders, flensers, and lemmers (meat cutters).

The blubber is handled in three ways: open-cooking, pressure-cooking in a grid digester, and pressure-cooking in a rotary digester.

Open-cooking is the oldest method. As it is one of the best, it is still in use at some shore stations. However, it cannot be done with any degree of modern efficiency aboard ship (though this was the old way of rendering blubber on sailing ships). The blubber is minced or hogged and dropped by gravity or raised by conveyor into a large tank where it is cooked with open steam over several feet of water for about 4 to 6 hours at about 356° F (180° C). The oil is then cooled somewhat and the sediment allowed to settle before pumping the oil through a lowering pipe to separating tanks. A second cooking can be given the residue, with or without the addition of some caustic soda or sodium sulfate to aid in the digestion of the solid material. Such a method involves inexpensive equipment, is not time consuming, and produces an excellent, light-colored oil of very low, free fatty acid content. The temperatures and pressures are obviously desirably low.

Pressure-cooking of blubber by a grid digester is done in a large, vertical, cylindrical cooker with filling-door on top, emptying-door low down on one side, and a fixed pipe to tap off the oil as the blubber is steamed under pressure. A

blow-down valve is located at the bottom to lower the accumulating stickwater below the oil outlet. The blubber is not hogged, but deposited in large chunks of 10 to 20 pounds or so. About every 3 feet the mass of blubber is separated by steel grids which are placed within as filling proceeds. This prevents the contents



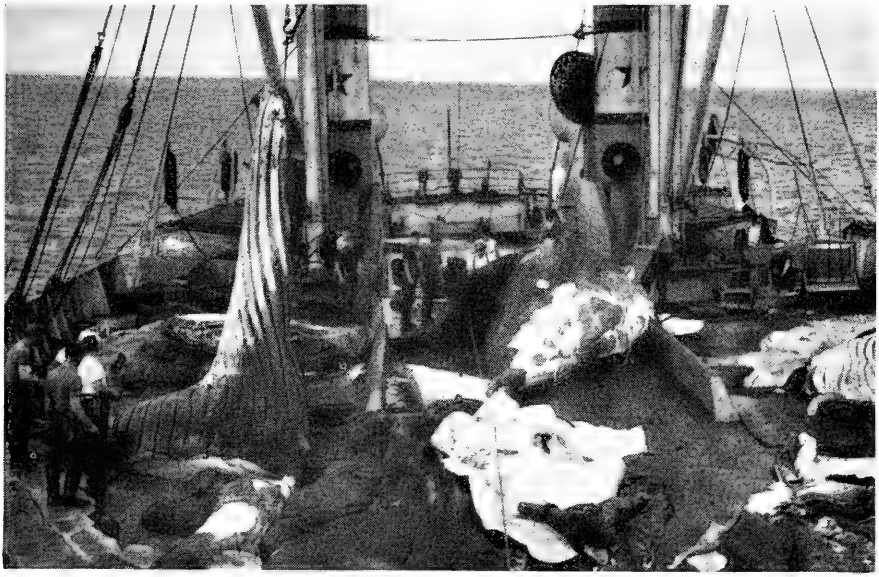
(Courtesy U. S. Coast Guard)

Fig. 33–3. Whales are pulled up the ramp of the factory ship by a winch-operated cable and whale claw.

from "balling up" and blocking the penetration of steam with subsequent building of extremely high pressures. Cooking takes about 18 hours, and the oil flows off continuously as long as the stickwater and graks are blown off below the level of the oil pipe. When finished, the graks are removed by hand from the bottom, the grids and digester cleaned, and another batch deposited. Pressure should be less than 60 pounds per square inch because higher pressure means higher temperature with subsequent scorching of the oil and raising of the free fatty acid content. This grid-digester method is the least efficient of the three as it takes a long time

to fill the cooker and cook the blubber, and must be carefully watched to prevent damage to the oil. The 2 doors are bolted tightly shut at time of cooking, and the whole digester is insulated with a special jacket to prevent loss of valuable heat.

The latest method for rendering blubber is the continuous rotary digester. This is an enormous horizontal cylinder with precookers at each end and an oil separator attached. Inside there is a rotary drum with perforations and baffle plates.



(*Courtesy U. S. Coast Guard*)

Fig. 33–4. Whale carcasses are flensed on deck of factory ship.

Large chunks of blubber are placed in the precookers. When the pressure rises in the precooker, the material falls automatically into the digester, and is then quickly and efficiently broken up into oil, water, and graks by the live steam and the mechanical action of the rotary drum. The entire fluid brei passes over to the separator under pressure during the digestion, and the oil is separated there by an ingenious gravity arrangement. The huge precookers can be filled as fast as the material is digested, which is from 2 to 4 hours per filling. The whole process is continuous, and with the help of agitation the temperatures and pressures remain low enough to give a good quality of oil. This continuous rotary apparatus is standard equipment on all modern factory ships, and is gradually beginning to replace the old vertical, batch, pressure, grid digesters at shore stations. However, they are expensive and require a large amount of raw material to make up for the cost of their installation.

Hogging and mincing blubber will aid in digestion, and is necessary in the case of open-cooking. In the continuous rotary digester hogging is unnecessary because disintegration is accomplished by the rotating drum with baffle plates. Blubber is tough and cannot be minced in the ordinary slaughterhouse prebreaker,

but must be put through a knife cutter or crushed between corrugated rollers under great pressure.

Hogged or minced material can be conveyed by bucket and bar conveyors, never by the chain because the fibrous material is tough and slimy and immediately gums any chain conveyor. A great deal of oil exudes during the process.

Cold-rolling and pressing, without the application of heat, has been tried, especially in Japan, in the reduction of oil from blubber, but is not yet a perfected method.

Meat is not mixed with blubber though the great layers of pure fat from the viscera may be thrown in. Not even the grooved blubber from the throat and chest of rorqual and humpback whales should be placed with blubber lest the slight amount of meat in the thin muscle of this area color the oil and raise the free fatty acid content. The grooved blubber can be digested with bone.

Oil is separated from the water and fiber by gravity-water separators and centrifuges. The simple gravity-water separator can hardly be utilized on shipboard though a modification of it exists on the rotary digesters to separate the crude brei into oil and residue. At a shore station there may be a series of 2 to 4 gravity separators in tandem. The oil, after settling for a time in the first, is spilled into the second by pumping water at the bottom. The process is repeated several times until the oil is practically pure. However, a whirl in a centrifuge helps to remove practically all of the moisture and sediment which may later give trouble in storage. Some shore stations centrifuge only the sludge from the first gravity separation and the stickwater from the digester.

Factory ships use a whole battery of special whale-oil centrifuges—enough to take all the maximum oil production from the continuous rotary digesters without storing uncentrifuged oil. Sometimes the oil is filtered before centrifugation. After centrifuging, all the oil is stored.

Emulsified oil and water from improper digestion or from the presence of watery fat has to be discarded or handled in special emulsion-breaking centrifuges. Breaking of emulsions depends more on the size of the oil droplets than on the force of the centrifuge; the finer the droplets the harder to break is the emulsion.

Oil should never be stored for any period without being refined to remove all the moisture and free fatty acid. Then it should be kept in the dark, at low temperatures if possible, and away from moisture or moving air. Storage underground or in high altitudes gives desirable low temperatures, and replacement of air by nitrogen over the oil helps prevent oxidation. All protein fibers are automatically removed with the moisture during filtration and centrifugation.

Cooking meat for meat meal and oil is also done by several methods. The simplest is to mince or hog the meat in a prebreaker, cook it for a short time in an open pot over water with live steam, then tap off what oil is present, and press, dehydrate, grind, and sack the residue. The oil from the pot and press goes to the oil separators, and the stickwater to its own treatment. Another way is to deposit large chunks of the meat in a batch grid digester and cook them for 18 hours or so under 55-pounds steam pressure. This is the slowest and most inefficient way; the stickwater is blown off at the bottom and the oil comes off in small quantities during the digestion. The graks are shoveled out by hand after the digester has been cooled and opened. Grids in the digester are absolutely necessary as they

prevent solid packing of the material. The oil is of poor quality—high free fatty acid and high color.

Both methods of cooking predominate at old shore stations, and the cooked and pressed meat is handled in the regular press and the fish-reduction type dehydrator. Generally the press is of the continuous screw type, which handles the wet, sticky meat less well than the apple-type press of 2 canted, perforated plates. Dehydration is usually done in a long, large, cylindrical, canted, flame dehydrator which, as it revolves, passes the wet coarse meat from the slightly higher flamed end along its baffle plates to the lower end. After this process the meat is in the form of a lumpy dried meal.

Meat should be fresh. The oil in meat deteriorates much faster than oil in blubber, and the meat itself becomes so slimy and clayey that the presses can hardly handle it and the dehydrator cannot perform efficiently. However, raising the flame too high to handle difficult meat or to dry it thoroughly makes a grave fire hazard.

The oil content of whale meat is rarely above 10 per cent, except in late pregnant females when it goes to 25 or 30 per cent; frequently it is below 5 per cent. Lean meat will actually absorb oil if any fat from blubber scraps, viscera, or groove blubber is intermixed. In such cases the oil content of the meal may rise to 10 or 12 per cent, causing it to dry and grind with difficulty and to become rancid in storage. Fat content in meat of less than 3 per cent is not considered recoverable.

Factory ships formerly discarded the meat, cooked or uncooked, but lately have been saving much of it for fresh food, meat extract, and powdered meal. For meal, the meat is usually minced, simmered for a short time at low temperature (below 100° C), and then passed through step or shelf dehydrators after the small amount of oil has been separated from the top of the cook. It is then ground and sacked, and transferred to transport ship at sea. Even later methods can by-pass the production of oil and meat extract and mince and dry in vacuo before grinding and sacking. There is a close inverse relationship between the water and the oil content of whale meat, which allows the latter to be quickly determined by a fast test for the former and extrapolation. This can be done in 15 to 30 minutes before the carcass passes from the flensing deck forward to the meat deck. Today only the raw meat of sperm whales can be legally discarded.

Bones have a high oil content and must be utilized by law (except flippers). The ribs and flipper bones are usually disarticulated; the vertebrae disarticulated or sawed; and the skull sawed with a steam saw.

Bones cannot be easily broken up on account of their size and the incredible hardness of some in the skull; consequently, they must be cooked in a pressure cooker. They are dumped helter-skelter in the old batch pressure cooker, and do not need grids because plenty of air spaces remain among the bones. They are steamed under 55 to 60-pounds pressure for 18 to 24 hours. The oil passes off continuously. When fresh material is cooked without being overheated, the resulting oil is of good grade. Too much meat adhering to the bone, especially from a rotted carcass, deteriorates the oil, as does too much pressure. The large chunks of bone are extracted by hand when the digester has cooled. The latest device for cooking bone is the rotary batch digester. This resembles the rotary continuous digester for blubber, except that there are no precookers and the digester must

be filled at one time, closed and cooked, then opened and refilled. The rotary drum, however, hastens disintegration of the bone and rendering of the oil so that the time of cooking can be reduced to about 4 hours; furthermore, a good grade of oil is produced. The entire residue passes off continuously as a fluid brei, and is separated at a gravity separator. Formerly the nonoil residue was discarded, but it is now separated from the stickwater, dried, and powdered for high-grade bone meal, as is also done with the whole cooked bone at a shore station.

The handling of viscera is subject to more opinions and techniques than other parts of the whale, and the law does not require its utilization. Glands, however, are sometimes removed and saved. The lungs are often discarded with the tongue, as are the intestines; but sometimes some or all of them are saved. Great layers of visceral fat along the mesenteries and around the heart, stomach, and kidneys are almost invariably saved. Probably the best way to handle the guts is to remove the glands and layers of fat, then push or haul the whole lot into an open gut tank where it can be steam-cooked with large amounts of caustic soda. The oil is dark red, but may contain much vitamin A. The caustic soda neutralizes much of the free fatty acid as well as breaking up the tissue. The tongue can often be handled with the bones and yield a recoverable amount of oil; however, it is exceedingly rubbery and hard to cut or hog.

Products

Products from the whaling industry may conveniently be separated into raw or primary products, and derived, processed, or secondary products. Further by-products of these are really part of the chemical industry.

Primary products are fresh or salted meat for human or animal consumption, baleen, ivory, ambergris, hides, and frozen glands for pharmaceuticals.

Secondary products are oils of all kinds, meat meal, bone meal, meat extract, liver oil, canned meat, etc.

Oil. The oil from a whale depends partly on the species and partly on the condition of the individual. Sperm and bottlenose yield waxy oil, the others glyceridic oil. Sperm, humpback, and blue whales, among the larger species, are the best producers. All individuals, particularly the late pregnant females, are fattest in late summer after 3 or more months on the feeding grounds.

A lean whale is distinguished by the thin body blubber with a watery inside layer, no leaf fat on the body just under the blubber, and the poor quantity of visceral fat. A fat whale shows thick body blubber, a firm and oily inner layer of body blubber, some leaf fat between the blubber and meat, and immense deposits of fat around the heart, kidneys, mesenteries, and at the base of the flipper (Tveraaen, 1935, and Klem, 1935). Blubber thickness is usually measured for standard on the side between dorsal fin and vent; but Slijper (1949) has proved that the thickness of the blubber at the side base of the dorsal fin better indicates the general condition.

Whale oils are graded on the basis of color and free fatty acid content. Generally the purchase order stipulates the maximum amount of both, and this is usually under 2 per cent free fatty acid and under 5 on the yellow scale of the Lovibond tintometer. Poorer grades are also sold as such, and formerly there were about 4 or 5 grades. Today most of the oil is No. 1, and as much poorer oil as possible

is mixed with the highest grade to meet the requirements of the contract. Properly prepared blubber oil runs about 1 per cent free fatty acid and under 2 yellow; bone oil runs under 3 per cent free fatty acid and from 8 to 10 red. Meat and gut oil are usually so poor that there is an excess which is sold separately, especially as it may have a higher content of vitamin A than the other oils.

Needless to say, the easiest way to obtain good oil is to process the whale as soon after death as possible (12 hours or at most, 24). Oil in the blubber will keep well on the carcass or in chunks for a week or so, but the meat, guts, and bones will deteriorate rapidly and give poor oil as well as become harder to handle in every way. The maximum legal time for holding a carcass before flensing is 33 hours.

Oil is sold by weight, not volume, though this has not always been the case. The prices today are quoted by the pound or by the metric ton, rarely by the gallon or barrel unless defined by weight. The common barrel of whale oil measures ⅙ of a long ton of 2240 pounds (equals 1016 kilograms), or 49.8 gallons U. S. A barrel of sperm oil of lesser density than whale oil would be slightly more than 50 gallons.

The weight of a gallon U. S. of whale oil is ordinarily considered to be 7.5 pounds, but may be from 7.62 to 7.7 pounds. A gallon of sperm oil weighs about 7.25 pounds, and would require more volume than whale oil to make a barrel.

Natural watch and fine instrument oils from the head and jaw of porpoises and dolphins have the least known and poorest economic situation. In the United States today only one firm produces such oil, which sells for about 75 cents a half ounce when refined, or about $192 a gallon straight refined. When crude, it may have a value of $15 to $30 per gallon. A synthetic watch oil has been manufactured since the early 1940's and sells for about $800 per gallon, or about $3.10 a half ounce straight.

Meat. Fresh meat from all cetaceans has been used for human consumption from earliest times. In Europe the flesh of dolphins and porpoises was once considered a delicacy, and could be substituted for fish on religious fast days. Whalers have always utilized all types of meat to relieve their monotonous ship's fare. However, Japan, Norway, and the Faeroes are the only modern countries which have long included whale meat in their national diet. Although during World War II England introduced whale meat to its people and sold a great deal, it will probably never replace beef in their eating habits. However, whale meat became so important in Norway and England in recent years that some discussion of this subject is necessary. Its popularity was the result of the scarcity of beef, pork, mutton, and fish, and not of any great demand for whale meat, though it is tasty and nutritious.

Species of Cetacean with Edible Meat. Without exception all species of whales are edible. The flesh of sperm and bottlenose whales has been claimed unpalatable on account of purgative action; but much sperm meat is eaten in Japan, and the bottlenose is eaten in Japan, the Faeroes, and possibly in Norway. The meat is much less purgative than the blubber because it contains less waxy oil, perhaps 45 per cent. Although "adaptation" is frequently necessary before the meat of these species is relished, it is certain that the meat of the younger individuals is much more palatable than that of old ones, as is the case with all species, and

that food or hormonal (breeding) factors may at times reduce palatability. It is also true that the species with predominantly glyceridic oils in the blubber and meat are the most palatable (they are most similar in this respect to our domestic animals). However, the blubber of the sperm, which may have a wax content of 65 to 85 per cent, is also eaten in Japan.

Treatment of the Carcass. The small carcasses of dolphins and porpoises can be hauled out and treated like large fish or fresh beef.

For the larger species the Norwegians employ both small-type and large-type whaling methods. The former method utilizes principally 25- or 35-foot minke whales. These are hauled on the deck of the small hunting boats and flensed; the meat is iced. Sometimes they are delivered to a larger ship.

In large-type whaling, sei and finback whales and some blue and humpback whales are used. Only the chest and tongue are inflated after death to prevent possible dissemination of bacterial organisms in the meat from ruptures in the intestines and from the opening of the belly wall to cool the body. The carcass is towed to a station where it is hauled out and flensed as usual; the top longissimus dorsi muscle along the spine is stripped, and large chunks of it are carted away in clean hand trucks. The meat never touches the deck. After the whale has been turned over, the other back muscle is similarly disposed of. Then, after the disarticulation of the ribs and evisceration, the inner backstrap muscles, the ilio psoas, are chopped in place and carted away. The throat, tail, and other muscles are used for fox food. All meat is trimmed, cut into large slices, and iced for delivery to the local markets. For distant delivery the meat is quick frozen.

In the Antarctic it has also been found desirable to slit the belly wall to cool the carcass, and to have the carcass hauled to the mother ship by a tow boat so that the time elapsed between death and butchering is shortened. The meat is cut into chunks and frozen on board, then transferred to a refrigerator ship.

The Japanese also salt a good deal of whale meat in the Antarctic for home consumption. Transfer at sea of the fresh meat to the refrigerator ship is effected by dumping the large chunks down a canvas tube into a lighter alongside, where it piles on rope nets that are hoisted up by the other ship. The meat is washed in sea water before salting or freezing on the refrigerator ship.

Cutting the body wall to allow sea water to cool the carcass enables it to be held from 18 to 24 hours after death without serious deterioration. Otherwise, 12 hours seems to be about the limit despite the latitude of capture and temperature of the water; the thick blubber insulates the flesh and allows autolysis and bacterial decomposition to proceed at much the same rate anywhere. However, the cooling of the body by sea water definitely slows decomposition.

Cutting the carotid arteries and the jugular veins at one side of the throat in front of the flipper helps to bleed the meat and gives a lighter-colored product, but it is not considered effective in prolonging preservation. Soaking the meat in cold brine for 24 hours helps to remove the blood, and also improves the flavor.

Lillie (1949) claimed that the regular use of whale meat for human consumption would become an economic necessity, and that the explosive harpoon ruined the meat for such purposes by rupturing the intestines and disseminating bacteria through the meat via the blood stream. He advocated the use of the electric harpoon as the only economical and humane way to kill a whale. His views have not been adopted yet, but it is very likely that the electric harpoon will become

popular, due as much to its possible efficiency in killing as to its role as a possible preserver of meat.

Grading and Inspection. In Norway and England the meat has been graded into Grade A (light red steaks), B (darker red steaks), and C (blackish meat). The first was said to be equivalent to the finest beef. Meat has also been graded into No. 1 (best cuts of back meat with connective tissue removed), and No. 2 (neck and tail meat with much connective tissue). Likewise, the following grades have been used: No. 1 (best steak meat from fillets of young whales trimmed of connective tissues), No. 2 (sausage meat from older whales with trimmings from No. 1), and No. 3 (fox food from belly muscles, shoulders, neck, and lower back with much connective tissue). Dark meat usually comes from the older animals and lighter meat from the younger; but, brine will lighten meat quickly.

As a matter of fact it is extremely hard to grade meat, except for first-grade steaks, second-grade steaks, and trim or chuck meat. The process of grading not only involves the species, age, and time elapsed after death until butchering, but also a test of palatability. This latter test cannot be done chemically, for each batch must be actually tasted, as is done with liquors and teas. The great trouble in this business is the inability to lead to slaughter the proper whale when it is prime.

A test for ammonia, which detects the number of bacterial organisms and hence degree of decomposition, has been devised to take place between the short time a whale is hauled aboard a factory ship for flensing and its arrival at the meat deck for butchering. Too high ammonia indicates the presence of too many organisms. As the meat is thus unfit for human consumption, it is consigned to meat meal.

Nutritive and Palatability Qualities of Whale Meat. Chemically, whale meat resembles beef. It has less fat, usually from 3 to 8 per cent instead of from 10 to 12 per cent. It also contains more amino acids, slightly higher quantities of anserine and carnosine, also creatine and lactic acid. The balanced amino acid content is an important factor in nutrition. The composition of whale meat has been determined by Bate-Smith and Sharp (1946) and Okuda, Okinoto, and Yada (1919).

Fishiness and oiliness are due to staleness, partial decomposition, and perhaps food factors of the whale. Otherwise, the meat tastes like coarse beef, veal, pork, or venison.

Economy of Whale Meat. In most places whale meat is definitely a substitute for beef, pork, mutton, fish, and other culturally integrated foods. In Norway and England, Iceland, and Canada it is considered second class even though it is high-priced. Already the accessibility of the usual meats is driving whale meat off the market in Norway and England; and, in Canada and the United States it has always been a novelty food, not a staple.

Only in Japan and the Faeroes (aside from the aboriginal cultures such as the Eskimo) is whale meat habitually eaten. In Japan the variety of edibles and the number of cetaceans so utilized is astounding.

England in 1948 brought 4000 metric tons of frozen whale meat from the Antarctic, and expected 7000 to 8000 tons in 1949. They also imported lesser quantities from Norway and Iceland. Much of the Antarctic meat was not re-

ceived favorably, due perhaps to ill effects of mass production without much previous experience in preparation on shipboard and in the home.

Norway, during the recent war and afterwards, produced much whale meat from local fisheries, and may have brought some from the Antarctic. In 1947 its domestic production in No. 1 steak meat was 4000 tons.

Canada produced a small quantity of fresh meat in 1948, but had difficulty marketing it in Vancouver, Victoria, and Seattle. Some was flown to distant United States "seafood restaurants" as a novelty meat. The United States produced none.

The future of whale meat (and that of porpoises and dolphins) in the occidental culture rests on integrating it as an economy food, grading it carefully by selection at the source, and testing its palatability.

Ambergris. This product results from a morbid digestive process of sperm whales, and is highly valued in perfumes as a fixative for odor. It also contributes a peculiar musky odor of its own. Formerly, it was prized mostly by Moslem peoples as a spice in tea, as an aphrodisiac, votive offering, specific in medicine, etc. Its rarity, unique composition, and fabulous value, imparted by real and imagined properties, make it one of the most famous natural products of the world. Probably more miscellaneous samples are submitted to public and private agencies to be tested for ambergris than for any other single substance, and only one out of hundreds will prove to be real ambergris. All this stems from the most common origin of ambergris, as flotsam and jetsam on the beach where it may be found by anyone. Interest in the search is sustained by an occasional find of ambergris, either in a large chunk or in a multitude of small particles. True ambergris may also be found floating on the surface of the open ocean or lodged in the lower intestines of a dead sperm whale where it originated.

Ambergris may be soft and waxy to touch or rather hard and friable, depending on its age and dryness. It can usually be kneaded in the fingers, and has the consistency of pitch, but is not sticky. In color it is black, gray-white, mottled gray and black, or brown and yellow, or any combination. It sometimes has an internal structure of concentric layers like an onion, and often has fragments of squid beaks or squid "bone." Its odor is fetid when fresh and dark-colored and musky in a sweet earthy way when older, drier, and lighter in color.

It melts at around 140° F (60° C) and volatilizes as white vapor at 212° F (100° C); is soluble in hot alcohol at 140° F (60° C) or in cold absolute alcohol, ether, and fatty and volatile oils, and the alcohol solution leaves a green-yellow fluorescent rim to the glass; it burns with a pale blue flame and characteristic resinous, musky odor, without leaving bubbles of scum or an ash; it floats in fresh and salt water.

Analysis indicates that it is a mixture of glyceridic esters (fats) of complex nature, with a waxy ester of the alcohol ambreine having the empirical formula $C_{23}H_{40}O$. It is the ambreine ester which gives it its peculiar properties and odor, though this has also been attributed to benzoic acid.

Tests for ambergris are: (1) melting point; (2) burning properties; (3) fluorescent properties of alcohol solution; (4) hot wire test (described below); and (5) microscopic examination which should reveal fragments of the chitinous beak of squid, and perhaps fragments of the calcareous "pen bone" or internal skeleton of certain species.

The hot-wire test was advocated by Morrison and later by Carter (1935). Heat a wire or needle for 10 to 20 seconds, insert for ⅛ inch, whereupon, if genuine ambergris, a dark resinous liquid forms on the wire and appears to boil. Withdraw the wire and, before cool, touch with finger; tacky pitchlike "strings" will adhere to the skin. When cold the ring of melted ambergris shines like dark enamel. Fire the ambergris over flame, and extinguish, noting a fatty or resinous odor to the smoke, often with slight odor of burning rubber.

Ivory. Ivory derives from the teeth of the sperm whale and, less commonly, from other smaller toothed species, such as the killer whale, narwhal, and white porpoise. It is used for carving of all sorts: chessmen, miniatures, combs, scrimshaws, etc. The spirally twisted tusk of the narwhal is a prized ivory trophy.

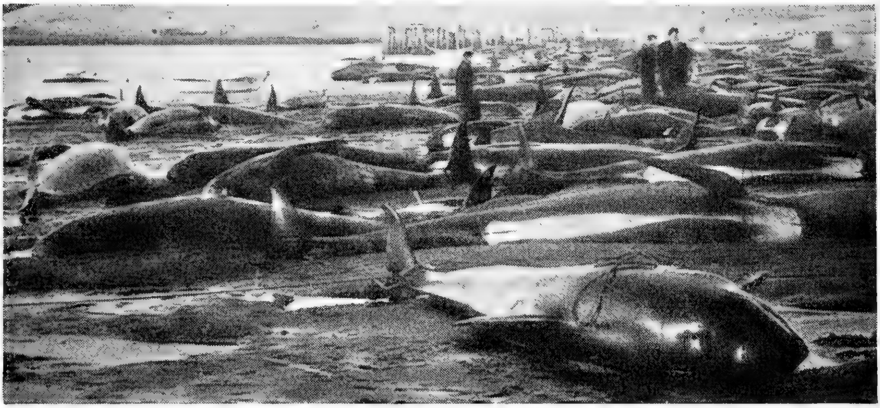
Scrimshawing was once one of the notable endemic traits of the sperm-whaling industry. The old-time whalers passed much of their leisure time on 2-, 3-, and 4-year cruises by carving and incising sperm whale teeth and slabs from the hard bone of the lower jaw. These objets d'art have since become prized bits of primitive Americana. They represented the details of this arduous, but romantic and soul-filling life.

Glands. A recent primary product of the whaling industry is frozen glands. Pituitary (hypophysis) for pituitrin and other hormones, thyroid for thyroxin, pancreas for insulin, adrenals for adrenalin and cortin, ovaries for ovarian (follicle) and luteinizing hormones, and testes for testosterone have been experimentally or commercially utilized, but the thymus and parathyroid remain unutilized. The thymus is present and obtainable, but is too little known physiologically in any animal to warrant collection from the whale. The parathyroid is exceedingly difficult to find. The large size and generalized mammalian structure and function of the glands allow for handling and processing by the packing and pharmaceutical houses, as are the comparable glands from cattle, sheep, and hogs.

Baleen (Whalebone). Baleen is the proper name for "whalebone," although it is also known as "fins," "bone," etc. It is the horny hard substance which hangs in long plates or slabs, shaped like knife blades, from the roof of the mouth on each side where teeth should be. Each plate is pointed and fringed on the inner side because of the frayed condition of the constituent fibers. The plates are placed one in front of the other like cards in a deck, and the fringed edges make a mat or sieve which strains out the small shrimp and copepods from the water and concentrates them for swallowing. The substance of whalebone is like that of the fingernail; it is keratinous, and consequently stiff, elastic, waterproof, and divisible by splitting into plaits or fibers as fine as desired. It was once very popular for dress stays, stiffeners of taffeta silk, and collars, buggy whips, and umbrella stays. The advent of steel "feather bone" came just in time to save the bowhead and right whale from almost complete extinction. These two species yielded the longest and finest bone, from 5 to 12 feet long. The fantastic high prices of $5.00 to even $7.00 a pound enabled a whaler to pay for a trip with 1 or 2 whales yielding 1500 pounds or more of "bone." Today it is discarded by the ton from all operations, nor has any substitute use been found, aside from trinkets, such as cigarette cases and baskets.

Hides. Whales, dolphins, and porpoises as a rule have a skin unsuited for leather because of the lack of compactness of the fibers; but the skins of the white whale, narwhal, and perhaps the common porpoise and bottlenose dolphin have been

used for leather. The first two in particular have a special structure of longitudinal fibers in a compact layer of the outer dermis which gives a superior leather. The skins of the other two are generally considered too thin and weak. At the close of the last century \$200,000 was roughly the annual value of "porpoise leather," which was almost entirely from the white whale (q.v.). The hides were cut in a right and left half, flensed, and salted. It is difficult to distinguish in the accounts of tanning and preparing of "porpoise" skins what species was under discussion;



(Courtesy U. S. Fish and Wildlife Service)

FIG. 33–5. A school of blackfish on the shore of Cape Cod.

in these cases it is perhaps well to consider it to have been the white whale, or secondly the bottlenose dolphin, or both. The narwhal is not taken regularly, nor, when taken, is used for its hide, which is turned into food by the Eskimo.

Oil. Oils from cetaceans of all kinds fall into two chemical classes: glycerides and waxes. Glycerides are compounds (esters) of 3 molecules of fatty acids and 1 molecule of the tribasic alcohol glycerol. The fatty acids are rarely the same; generally two different kinds are attached (molecular ratio 2:1), and sometimes three (1:1:1). Thus, in a glyceridic oil there are a number of glycerides involving a number of fatty acids of carbon content, from 16 generally to as high as 22, but only the single alcohol, glycerol, is present. Waxes on the other hand are combinations between 1 molecule of a fatty acid and 1 molecule of a higher monobasic alcohol, such as cetyl or oleyl. The fatty acids usually vary from C_{10} to C_{20}. Vegetable oils are glycerides, as are the tallows and fats from domestic animals. Fat is the solid form of the same type of substance as oil, which is the liquid form. Waxes also have liquid and solid forms.

Glyceridic oils are found everywhere among the cetaceans. No fat-bearing part of any species is without glyceridic oil, and the oil of most species and of all baleen whales is exclusively this type. Waxes, on the other hand, are found as the principal constituents of the oil of sperm, bottlenose, and beaked whales only, and also occur in small amounts in the smaller species of dolphins and porpoises which eat squid and dive deeply.

Whale oil is the general term for the glyceridic oils from baleen whales, and commercially may come from any one or several species mixed indiscriminately

at the whaling station or factory ship. The principal use is for margarine and glycerine in Europe; it hydrogenates as does a similar, partially unsaturated vegetable oil. In the United States the main use is for soaps and the production of glycerine. Consumption is limited because of the abundance of cheaper vegetable oils. Fatty acids are to some extent the by-products of the production of glycerine. However, all these usages and techniques are essentially a part of the chemical industry, not whaling.

Body oil from the white whale (beluga) is often referred to by that name, as is that from the blackfish (pilot whale). Similarly, body oil from various smaller cetaceans when they form an exclusive cetacean fishery are called by the species: porpoise oil (either from true porpoise, or bottlenose dolphin) or dolphin oil, etc. There is some confusion, however, over the head and jaw oil from dolphins and porpoises, and often the exact nature of the oil is not indicated by the name.

A peculiar form of glyceridic oil is found in the head fat (melon) and jaw-pan fat of dolphins and porpoises. This oil contains a high proportion of glycerides of isovaleric acid which gives the oil peculiarly good properties as a lubricant. The oil does not gum or stiffen at low temperatures, nor oxidize at high; it does not corrode metal or become acid. Properties of this oil are given in Table 153. Formerly it was the exclusive watch and fine instrument oil of commerce, though recently it has been replaced to some extent by a synthetic product. Generally these oils are referred to as head and/or jaw oils, or blackfish head oil, porpoise jaw oil, etc.; but sometimes the general term blackfish oil or porpoise oil is used to indicate the special head and jaw oils, and not a body oil.

Liver oils of all species, including the sperm, are mainly glycerides, but are not classed as whale oil because of the high content of vitamin A. This vitamin is usually esterified; but cholesterol, a cyclic alcohol, may also be present and give additionally unique properties to liver oil.

There is evidence of appreciable amounts of vitamin D and traces of vitamin A in cetacean blubber oils which may cause the alleged curative powers of the oils in dermatoses of various sorts.

Refining. Steamed whale oil is usually of excellent quality, and for many purposes does not need refining.

Table 153. Some Chemical and Physical Properties of the Oil of the Common Porpoise.

	Upper jaw (head melon)	Lower jaw	Skull	Blubber
Specific gravity at 77° F (25° C)	0.9360	0.9345	0.9186	0.9226
Refractive index at 77° F (25° C)	1.4529	1.4544	1.4650	1.4658
Iodine value	32.7	36.7	74.3	89.3
Saponification value	312	298.7	221.1	230.2
Reichert-Meissl value	136	130.9	19.6	33.9
Unsaponifiable matter	1.0%	1.1%	1.5%	0.6%
Viscosity at 77° F (25° C), Poises	0.46 P	0.5 P	?	0.51 P
Clouding point, clears at	−4° F (−20° C)	8.6° F (−13° C)	37.4° F (3° C)	6.8° F (−14° C)
Solidifying point, clears at	−4° F (−20° C)	3.2° F (−16° C)	25° F (−4° C)	−0.4° F (−18° C)

Note: The yield of oil from these 4 body sources was: Blubber oil 14 pounds (324 ounces), upper jaw (with melon) 3¼ ounces, lower jaw (pan fat) 2½ ounces, and skull (brain, etc.) 1½ ounces.

Source: Sunderland, P. A., "Analysis of Pacific Coast Porpoise Oils," Fisheries Research Board Canada, *Prog. Repts. Pacific Coast Stations,* **14,** 14–15 (1932).

TABLE 154. OILS OF COMMON PORPOISE (*"Phocaena communis"*) ANALYTICAL CONSTANTS.

Source	Iodine value	Sapon. value	Amt. Unsapon.	Nature of Unsapon.
Body blubber	88.82	225.7	2.4%	Mainly higher alcohols
Head blubber [= Melon?]	64.76	204.7	2.1	" " "
Jaw fat	44.93	196.3	3.6	" " "
Liver	175.0		32.1	Mainly cholesterol

Per Cent Weight Component Fatty Acids

	Saturated					Unsaturated				
	C_5	C_{12}	C_{14}	C_{16}	C_{18}	C_{14}	C_{16}	C_{18}	C_{20}	C_{22}
Body	13.6	3.5*	12.1	4.7		4.7 (—2H)	27.2 (—2H)	16.7 (—2.8H)	10.5 (—4.8H)	7.0 (—4.9H)
Head	20.8	4.1	15.8	7.5	0.2	4.6 (—2H)	20.8 (—2H)	15.2 (—2.6H)	9.4 (—4.5H)	1.6 (—4.7H)
Jaw	25.3	4.6*	28.3	4.1		3.2 (—2H)	20.3 (—2H)	9.3 (—2.6H)	4.9 (—4.9H)	
Liver			4.6	9.0	1.2	0.1 (—2H)	16.5 (—2H)	27.0 (—2.4H)	31.0 (—3.3H)	10.6 (—5.4H)

* Traces of Lauroleic Acid.
[columns for foetus omitted].

Source: Lovern, J. A., "Fat Metabolism in Fishes and Cetaceans. III. Selective Formation of Fat Deposits," *Biochem. J.*, **28**, 394-401 (1934).

In refining, the oil is heated in tanks by means of steam coils until all moisture is expelled. After heating from 6 to 10 hours the oil is allowed to settle and partly cool, during which process the solid impurities settle out. The purified oil is then drawn from the top of the tank into barrels and casks.

The oil is then chilled. In cold weather this is done by placing the barrels out of doors. At other times this is accomplished by artificial refrigeration. The congealed mass is usually dumped on wooden strainers. After the liquid oil has drained off, the residue is placed in canvas or hemp bags, holding from 2 to 4 gallons each, and subjected to great pressure. The first oil from the press congeals at 36 to 40° F (2.2 to 4.4° C), and is called "winter whale oil." The foots or stearin that remain in the bags average 1/10 the original bulk of the oil, and are usually white.

Some oil is bleached by treatment with caustic soda or soda ash, or by exposure in shallow vats to the action of sunlight, or by filtration through fuller's earth.

Composition and Properties. Whale oil resembles the slow-drying fish and fish-liver oils in many respects. The highly unsaturated fatty acids consist chiefly of clupanodonic acid, which is also found in fish and fish-liver oils, but there is a greater amount (30–45 per cent) of unsaturated C_{18} acids.

The iodine value of a given specimen of oil depends to a large extent upon the amount of "stearin" left in the oil since the "stearin" consists chiefly of palmitin, a saturated fatty acid. The deposited stearin has an iodine value of about 40. The amount of unsaponifiable matter in commercial whale oil varies from about 0.65 per cent to 3.72 per cent. As a rule the lower the quality of the oil, the higher the percentage of unsaponifiable matter. The characteristics of a number of samples of whale oil are presented in Table 155 (p. 705).

Use. Prior to the discovery of the process of obtaining kerosene by the distillation of petroleum, whale oil was extensively burned for illumination purposes. Today very little is burned as many other superior illuminants have been discov-

TABLE 155. CHARACTERISTICS OF VARIOUS WHALE OILS.

	Specific Gravity at 59° F (15° C)	Acid Value	Saponification Value	Iodine Value	Unsaponifiable
Antarctic right whale oil (American)	0.9257	0.56	183.1	136.0	1.46
Whale oil No. 1, unrefined (Finmarken)	0.9181	0.86	188.6	104.0	2.36
Refined (Glasgow)	0.9214	1.4	184.7	113.2	2.33
Arctic whale oil, refined (American)	0.9234	1.9	185.0	117.4	2.11
Crude white whale oil (American)	0.9222	2.5	183.9	127.4	1.37
Whale oil No. 2, unrefined (Finmarken)	0.9182	3.6	188.3		3.3
Yellow whale oil, refined (Glasgow)	0.9232	10.6	185.9	110.0	1.89
Whale oil No. 3, refined (Finmarken)	0.9162	26.5	185.7	96.0	2.42
Brown whale oil, refined (Glasgow)	0.9272	37.2	160.0	125.3	3.22
Whale oil No. 4, unrefined (Finmarken)	0.9205	58.1	182.1	89.0	3.4
Dark whale oil, refined (Glasgow)	0.9170	98.5	178.3	103.1	3.03

ered. Large quantities are hardened and deodorized by hydrogenation. Hardened whale oil is extensively used in the manufacture of candles, soap, and lard substitutes. While hydrogenated whale oil is more nearly colorless and odorless than most hardened fish oils, it is inferior to the latter for use in the preparation of soaps as such soaps do not possess the best lathering properties. Hydrogenated fish and whale oils were marketed in large quantities and under various trade names in Germany before World War II.

The lower qualities of whale oil are employed in the currying of leather, as a lubricant, for tempering steel, as a "batching oil" for jute, etc.

Waxy Oils. The liquid semisolid waxes come principally from the sperm, bottlenose, and beaked whales. Although smaller amounts are found in other toothed cetaceans, especially in those which dive deep for squid, no commercial production of waxy oils is realized from them.

Today the sperm oil from the whaling station is a mixture of sperm oil and spermaceti; in other words, it is a mixture of oil from the body blubber which is largely liquid, and that from the head which is largely semisolid spermaceti. Formerly, these were kept distinct as body oil and head oil. Oil from the bottlenose and beaked whale is called bottlenose oil, arctic sperm oil, doegling oil, pothead oil, etc. Spermaceti from these species is not distinguished from that of the sperm whale when separated from the crude.

The liquid part, or sperm oil proper, is separated commercially into a number of fractions with different component wax esters and slightly different properties,

principally different clouding points (at which they will begin to deposit stearin). Spermaceti is the semi-solid fraction of the crude oil, the "foots" or stearin of commercial sperm oil. There is also a glyceridic fraction in all sperm oils comprising about 15 to 30 per cent, depending on the fraction under consideration or the composition of the crude (body blubber only, or body and head combined).

When the crude sperm oils arrive at the refineries, they are usually mixed in their natural proportions (viz., ⅓ head oil and ⅔ body oil) and treated together. The chief operation of refining is that of the separation of the spermaceti from the sperm oil, which is effected by prolonged refrigeration and subsequent pressing of the partially solidified mass. The crude sperm oil is allowed to stand in refrigerating chamber or out of doors from 10 to 14 days at a temperature of 32° F (0° C). The oil is then separated from the crude spermaceti by pressure in an hydraulic press. The clear oil, thus obtained, is known as "winter sperm oil"; according to the usual commercial standards this grade must not congeal at 38° F (3.3° C). Usually the amount of winter sperm oil obtained is about 75 per cent of the weight of the crude oil. This oil is bleached, usually by filtration through fuller's earth, before it is marketed.

The residue from the pressing of the winter sperm oil is again pressed at a higher temperature (from 50–60° F [10–15.6° C]); the oil obtained is called "spring sperm oil" and solidifies at 50 to 60° F. About 9 per cent of the total crude sperm oil is obtained as spring sperm oil.

The press cakes are stored for several days in rooms about 80° F (26.7° C). After trimming they are again pressed, whereby a third grade of oil ("taut-pressed oil") is produced, which solidifies at a temperature of 90 to 95° F (32.2 to 35° C). A relatively small amount (about 5 per cent) of this oil is obtained. The residue in the press cloth is crude spermaceti of a brown color, and constitutes from 10 to 12 per cent of the crude sperm oil.

Sperm oil differs from fish, fish-liver, and whale oils in that it consists chiefly of waxes and not of fats. Waxes are esters of fatty acids and monovalent alcohols. Upon hydrolysis, sperm oil yields from 60 to 65 per cent of fatty acids and from 35 to 40 per cent of monovalent aliphatic alcohols. Since the liquid fats contain about 95 per cent of fatty acids, this characteristic serves to distinguish the liquid waxes from all fatty oils. The specific gravity of these waxes is much lower than that of whale oil and other marine animal oils.

Sperm oil absorbs very little oxygen from the atmosphere. Its viscosity is not influenced by variations in temperature to as great a degree as fatty oils. Because of these properties it is a valuable oil for many lubrication purposes.

The most comprehensive work on the chemical composition of sperm oils is that of Hilditch and Lovern (1928, 1929a, and 1929b). They made the following observations:

(1) Head oil esters contained: Wax 74 per cent and glycerides 26 per cent. Blubber oil esters contained: Wax 66 per cent and glycerides 34 per cent (Tables 156, 157, and 158).

(2) The amount of palmitoleic acid in blubber oil was the largest of any known animal, and this fact plus the high amount of low unsaturated acids (monoethylenic) and low amount of high unsaturated acids of C_{20} and C_{22} should make (when partly hydrogenated) soap material superior to ordinary hardened

TABLE 156. PROPERTIES OF SPERM OIL.

	Head oil [Spermaceti]	Blubber oil
Consistency at 59° F (15° C)	Semisolid, very soft wax	Thick, fluid oil
Saponification equivalent	393.4	433.4
Acid value	0.8	0.3
Iodine value	60.1	85.6
Unsaponifiable material (including higher alcohols)	39.3%	33.6%

Source: Hilditch, T. P., and Lovern, J. A., "The Head and Blubber Oils of the Sperm Whale. I. Quantitative Determinations of the Mixed Fatty Acids Present," *J. Soc. Chem. Ind.*, **47**, 105T–111T (1928).

TABLE 157. GENERAL COMPOSITION OF SPERM OIL AND SPERMACETI.

	100 g head oil [crude spermaceti]	100 g blubber oil
Alcohol content	39.3	33.6
Fatty acid equivalent to alcohols	36.9	34.2
Combined as wax esters	73.4	65.7
Balance of fatty acids isolated	25.1	31.8
Corresponding weight as triglyceride	26.5	33.3
Wax esters	73.5%	66.0%
Glycerides	26.5%	34.0%

Source: Hilditch, T. P., and Lovern, J. A., "The Head and Blubber Oils of the Sperm Whale. I. Quantitative Determinations of the Mixed Fatty Acids Present," *J. Soc. Chem. Ind.*, **47**, 105T–111T (1928).

TABLE 158. COMPOSITION OF SPERMACETI ("HEAD OIL").

ACIDS (62 parts) — ALCOHOLS

Saturated 27 pts
- 2 pts glycerides — Glycerol
- 13 pts esters of unsaturated alcohols — 14 pts [*sic*]
- 12 pts esters of unsaturated alcohols or saturated-unsaturated glycerides — 9 pts

Saturated 23 pts

Unsaturated 35 pts
- 9 pts esters of saturated alcohols
- 26 pts
  - esters of unsaturated alcohols [4 pts]
  - Unsaturated or unsaturated-saturated glycerides [22 pts] — Glycerol

Unsaturated 16 pts

Fatty alcohols 39 pts [*sic*]

Source: Hilditch, T. P., and Lovern, J. A., "The Head and Blubber Oils of the Sperm Whale. II. Investigations of Some of the Component Wax Esters and the General Structure of the Oils," *J. Soc. Chem. Ind.*, **48**, 359T–365T (1929).

whale oil acids; but the presence of higher alcohols rendered utilization of sperm oil in this direction difficult, and hence unlikely to be practiced.

(3) The fatty alcohols (higher monobasic alcohols) were principally cetyl (saturated) and oleyl (unsaturated).

(4) The head oil contained nearly 30 per cent fully saturated wax esters and glycerides, while blubber oil had only 2 per cent.

(5) Head oil showed a distinct tendency for fully saturated wax esters to be formed from acids and alcohols of low molecular weight. Thus the chief constituents of spermaceti were cetyl myristate and cetyl laurate, rather than cetyl palmitate as generally claimed. Twenty-six per cent mixed glycerides of component fatty acids were also found.

(6) The main esters of blubber oil were evidently oleyl oleate and cetyl palmitoleate (hexadecenoate), together with 34 per cent mixed triglycerides.

(7) Head and blubber oil were heterogeneous, a characteristic frequently observed in animal oils.

(8) Spermaceti and sperm oil hydrogenated readily, and with sufficient demand for a spermaceti wax either spermaceti or sperm oil could be converted into more solid waxes. In hydrogenation oleyl alcohol and other combined unsaturated alcohols were converted into octadecyl or other saturated alcohols concurrently with the saturation of the fatty acid residues.

(9) Completely hydrogenated spermaceti yielded a white, close-grained, more solid spermaceti wax, which melted at 109° F (43° C) and had very little apparent greasiness. It may have a useful outlet in industry.

(10) Completely hydrogenated sperm oil (blubber oil) was a hard, lustrous, pure white spermaceti wax melting at about 129° F (54° C). This higher melting point over hydrogenated spermaceti was due to the larger amounts of octadecyl alcohol and palmitic and stearic acids present.

Spermaceti wax, when crude, is a soft, white wax, soon becoming crystalline. Pure spermaceti is used for cosmetics and medicinals.

Liver and Liver Oil. The liver of cetaceans is large: 500 to 1000 kg for the larger species. It contains little oil (averaging from 2 to 5 per cent), but this oil may be high in vitamin A. Vitamin D is absent or present in minute quantities only. Bailey (1942) got extremely low oil amounts (1 per cent or less) from finback, sperm, and beluga livers. The liver oil of all species, including sperm, is glyceridic.

The whaling industry ordinarily delivers only the chopped and frozen or salted livers in bulk; but some factory ships have their own equipment to extract the oil, thus saving much space in transportation and storage. Ash (1947) wrote that there was a loss of vitamin A on the surface of salted and frozen livers; that drying liver was difficult because of its sticky nature; and that the best way to prepare liver in bulk was to mince and press it between steam heated rollers. The latter process removed about 40 per cent of the 75 per cent moisture, producing flakes which were sealed in drums with air removed hermetically to prevent mold growth and oxidation of the vitamin A on the surface of the flakes. Processing liver for oil was done on board ship by the solvent method, using trichlorethylene. However, despite the greatest precautions there occurred in the processing unexplicable losses of vitamin A potency.

The Japanese factory ships mince the liver, mix it with fresh water, cook it

with caustic soda, and separate the vitamin A-bearing oil in a Sharples centrifuge (Anon., 1949b).

As numerous investigators do not agree on the amounts of oil (fat) in the liver and the potency of vitamin A in different samples from even the same species, there must actually be a great deal of variability in these two matters. The determination of vitamin A is complicated by the presence of "kitol." This factor is similar to vitamin A into which it can be converted, and it absorbs ultraviolet light of wavelength 328 Ångstrom units like vitamin A, but is not absorbed by animals. Hence, it gives falsely high values for vitamin A (Swain, 1949).

The general values of livers, oil, and vitamin A were summarized by Braekken (1948), who brought back many samples from the Antarctic.

	Av. per cent oil in liver	Av. potency Vit. A in g liver	Av. potency Vit. A in g oil
Sperm (all bulls)	5.54	4,880 I.U.	83,700 I.U.
Blue whale	4.08	3,950 I.U.	91,100 I.U.
Finback whale	3.83	1,170 I.U.	27,600 I.U.

For the ordinary "porpoise" Bailey (1941) found 20,000 to 30,000 Blue U. per g of liver, and for the white porpoise, or "beluga," he (1942) found 6,000 and 14,000 USP units per g of oil in two samples. In the Pacific white bellied porpoise Sanford and Kenyon (in Scheffer 1949) found 4,150, 19,500, and 25,800 units (I.U.) per g (liver) in three samples.

Braekken also determined that vitamin D was almost absent (0.75 I.U. per g of oil from blue and finback whales), but that the vitamin B complex of thiamine, riboflavin, and niacin, with a potency equal to that of beef, was present in finback and blue whale liver. The antianemic factor was absent, however.

Meat Meal. Since meat of whales and other cetaceans, outside of Japan, Norway, and the Arctic, is not usually consumed by humans or animals, it is converted into meat meal. Freshness of the whale is important for good meal; otherwise decomposition of the meat destroys some of its nutritive value and renders it clayey. Since the protein content is about 90 per cent and the balance of amino acids is good, the meal is a valuable addition to prepared cattle and other animal foods. The German army was fed whale-meat meal in successful nutritional tests just before World War II. The 10 per cent moisture content of the meal may cause spontaneous combustion in storage, but to attempt to obtain meal too dry may mean a fire in any flame dehydrator. High temperatures and pressures in processing are bad.

Turrentine (1915), basing his observations on an analysis by J. R. Lindemuth, noted the nitrogen (11.59 per cent), phosphoric acid (0.94 per cent), moisture (5.41 per cent), and oil content (12.8 per cent) of whale meal. The oil content was higher than that of most lean meat and probably was picked up from some chance admixture of fat in the processing.

Whale meat is almost invariably cooked and pressed for some oil. Even if the oil content in the meat is under 3 per cent, the meat must be partially cooked and pressed of its moisture to make meal. IWR require that all the meat of whales shall be utilized, except that of the sperm whale.

Ney and Tarr (1949) have found the recently recognized "animal protein fac-

tor," APF, in both wet and dry Norwegian whale meat (wet, 59 micrograms per pound; dry, 140).

Bone Meal. In the early days raw bone was discarded fresh because it was too bulky to handle and cook. However, with the advent of the pressure cooker it was converted into oil and bone meal.

The cooked bone from the old pressure digesters was pulled out by hand, easily dried, and then powdered and sacked for bone meal. Bone meal makes a fine fertilizer, especially when mixed with meat meal in a 30:70 ratio. Turrentine (1915) observed that bone meal had 3.01 per cent nitrogen, 26.08 per cent phosphoric acid (P_2O_5), 2.53 per cent moisture, and a trace of oil. The oil content of any fertilizer should be low.

Bone from the rotary digester comes out as a fluid brei, which must be specially handled so that it will make suitable powdered bone meal. It is usually discarded from factory ships.

Blood Meal. Blood meal is occasionally mentioned as a product of the whaling industry, but it is not common. Most whales become exsanguinated from their wounds, but occasionally one will retain much or all of its blood until the thoracic and abdominal cavities are opened. In this case the outpouring blood can be saved in the scuppers and sumps, and dried and powdered into meal. The blood content of cetaceans is higher than most mammals, and amounts to perhaps 6½ per cent of the body weight (Laurie, 1933). The chemical composition of whole blood and serum of sei and sperm whales and "dolphin" was given by Sudzuki (1924).

Canned Meat. Occasionally a whaling station will can whale meat for human or animal consumption. This has been done in the United States, Canada, and New Zealand, and on some factory ships. The product has never been very popular though it can be made as tasty and nutritious as canned beef.

In preparing whale meat for canning the meat is held in mild pickle for about 36 hours, cut for 1-pound tall cans, which are processed for 80 minutes at 220° F (104.4° C) after sealing.

Meat Extract. Several factory ships have recently produced a meat extract which Jacobsen (1949) considered to be rich in vitamin A. However, Ash (1947) did not mention any vitamin content, but believed that the creatine content was the important ingredient and the basis of the price. He stated that the liquors remaining after the blubber and bone have been cooked and the meat pressed were combined; that the gross particles were removed by vibrating screens; that the oil was then separated and the remaining particles filtered (exceedingly difficult); and that the remainder was evaporated until the water content was 20 per cent and the pH adjusted to that of fresh meat. About half of the creatine of whale meat was converted into creatinine during processing, and the creatinine was a measure of overheating during evaporation. The product was canned.

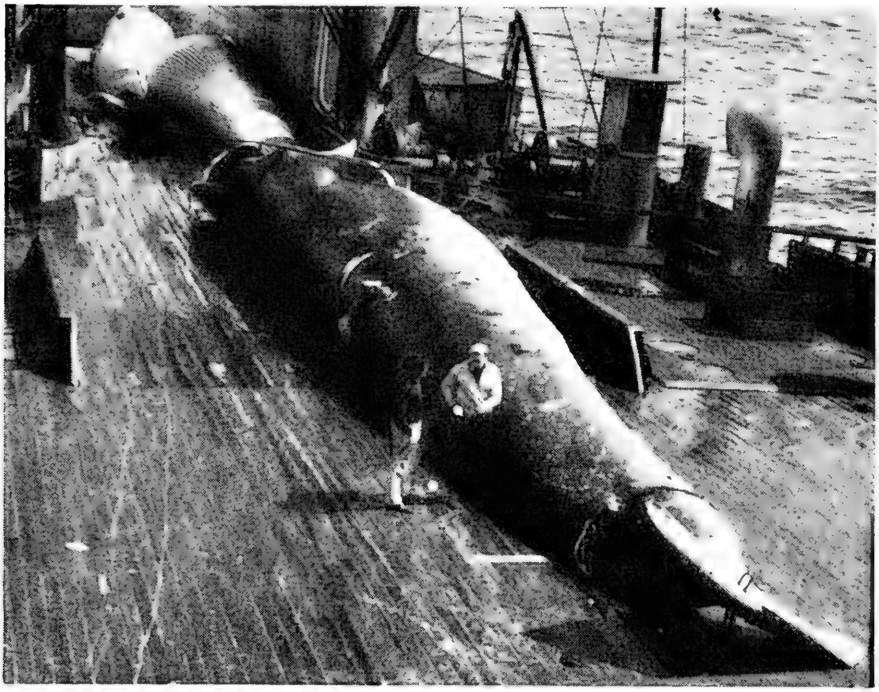
Gelatin from Stickwater. The gelatinous liquid from the cooks, after extraction of any traces of oil, is "stickwater." This gelatin fails to make a good glue, but contains a quantity of valuable proteins and special growth factors.

Formerly, the stickwater was allowed to cool in an open, outside tank, and the gelatinous scum taken off, cut in strips, and dried on wire frames. More modern methods of separating the fibers by vibrating screens and centrifuging the remaining liquid are found on some recent factory ships; but the installation of

modern apparatus is so expensive that it is only economically feasible for large operations with heavy continuous production.

The Factory Ship

Today the ultimate in whale-processing equipment, method, and technique is the factory ship. This floating factory may be 600 feet and 30,000 tons gross. It can provide living quarters and 24-hour work space for 450 men, and carry sufficient apparatus to handle 50 tons of raw material, or one ordinary whale,



(Courtesy U. S. Coast Guard)

FIG. 33–6. Finback whales on flensing deck of factory ship in the Antarctic.

per hour. The whale is hauled aboard through a ramp in the stern, and flensed and dismembered on the main deck, aft and fore respectively. Below deck are the batteries of rotary pressure digesters for the blubber and bone, and the many centrifuges and other equipment for complete utilization of the whale, all interlaced and connected by miles of pipe and powered by steam and electricity. Huge vacuum evaporators supply fresh water to the boilers.

Such a mammoth installation requires from 6 to 8 catcher boats to supply whales, and also tankers to remove whale oil and bring fuel, and transport ships to take off meat, meat meal, bone meal, etc. Corvettes for special tow boats make up the fleet. Storage space on the floater is at a premium, and is given over largely to apparatus and oil tanks. About 8 ships have been built in European shipyards since World War II (Norwegian Whaling Gazette, 1946, 1947, and 1948).

In 1948–49, the latest year for figures published by the International Whaling Statistics, 18 floaters operated in the Antarctic. Elsewhere in the world in 1949 a British floater under American contract operated off the west coast of South America, 1 or 2 Japanese boats off the Bonins, and a Soviet ship in the N. Pacific-Bering-Okhotsk region.

The Shore Station

The shore station is considerably less expensive than the floating factory, but it is also considerably smaller and more limited in range. About 100 miles is considered the usual maximum working range for the 3 to 6 catcher boats usually attached to a shore station. However, it can also be very efficient if it combines fishing operations and fish-waste reduction with whaling activities.

Requirements for a successful station, besides a good market, efficient management, and proper equipment, are (1) plenty of fresh water, (2) deep and quiet anchorage for the catcher boats and whale carcasses, (3) not too steep or narrow a shore for hauling the whales up the ramp to the flensing deck, and (4) plenty of whales within 100 miles for at least 4 to 6 continuous months.

In 1948 39 shore stations were in operation, including 3 on South Georgia in the subantarctic of the Atlantic, 1 or 2 in Brazil, 1 in Australia, besides the usual ones in Norway, the Faeroes, Iceland, Greenland, Newfoundland, California, British Columbia, Chile, South Africa, New Zealand, and Japan. In Japan alone there are perhaps 15 stations to take care of practically all the local species of cetaceans, large and small, for complete utilization by her intense economy.

Whaling Regulations

Whaling of the larger species: Sperm, sei, Bryde's, finback, blue, and humpback is regulated by the International Whaling Regulations (IWR). At present these are based on the Schedule of the Washington Convention of December, 1946, and the several modifications of the Whaling Commission inaugurated in June, 1949. The Commission alone, by due process, can modify the law today, and the cumbersome, formal treaty is no longer needed (International Convention, 1946).

National whaling laws also exist; and if they were enacted by a High Contracting Party to the Washington Convention of 1946, they follow the Schedule and subsequent modifications of the Commission. The U. S. national whaling laws are known as the Joint Regulations of the Secretary of the Treasury and the Secretary of the Interior (50 C.F.R., Part 251). These laws are subject to later international regulations, and contain additional restrictions.

REFERENCES

Anon., "Ambergris," *Chem. Trade J.*, and *Chem. Eng.*, **74** (1924). Reprinted in U. S. Fish and Wildlife Service, *Fishery Leaflet*, **280** (1948).

Anon., "Whale Meat," *Food Industries*, **21**, No. 1, 81–82 (1949a).

Anon., "Equipment and Processing Methods Used by Japanese Antarctic Whaling Expeditions," Gen. Hdqt., SCAP, Tokyo, Nat. Resources Sect., *Weekly Summ.*, **171**, 16–22 Jan. (1949b).

Anon. (Terry, W. M.), "Porpoise and Dolphin Fishery (Small Whale Fishery)," Nat. Res. Sect., SCAP, Tokyo, *Weekly Summ.*, **208**, 6–7, 2–8 Oct. (1949c).

Armstrong, E., and Allan, J., "A Neglected Chapter in Chemistry: the Fats," *J. Soc. Chem. Ind.*, **43**, 207T–218T (1924).

Armstrong, E. F., and Hilditch, T. P., "The Constitution of Natural Unsaturated Fatty Acids. Part II. Some Acids Present in a South Georgia Whale Oil," *J. Soc. Chem. Ind.,* **44,** 180T–189T (1925).
Ash, C. E., "Science in Whaling," *Research J. Sci. and Applications,* **1,** No. 2, 61–67 (1947).
Bailey, B. E., "Vitamins A and D in Whale Livers," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **51,** 18–19 (1942).
Bate-Smith, E. C., and Sharp, J. G., "Whalemeat," *Food Mfgr.,* **21,** No. 9, 371–377 (1946).
Braekken, O. R., "Vitamins in Whale Liver," Hvalradets Skrifter, *Sci. Results Marine Biol. Research,* Oslo, Det Norske Videnskaps-Akad. i Oslo, **32,** 125 (1948).
Brandt, K., "Whale Oil. An Economic Analysis," Food Research Instit., Stanford Univ., Palo Alto (Calif.), *Fats and Oils Studies,* No. 7 (1940).
Brocklesby, H. N., Editor, et al., "The Chemistry and Technology of Marine Animal Oils with Particular Reference to Those of Canada," Fisheries Research Board Canada, *Bull.,* **59** (1941). With B. E. Bailey, N. M. Carter, K. F. Harding, L. I. Pugsley, W. A. Riddell, N. I. Rogers, and L. A. Swain.
Brunelli, M. G., "Industrial Biology of Dolphins," *Comm. Internat. l'Explor. Scient. Mer Medit., Rap. Proc.-berb. Reunions,* **6,** 167–174 (1931).
Carter, N. M., "Ambergris," Fisheries Research Board Canada, *Prog. Repts. Pacific Coast Stations,* **26,** 19–20 (1935).
Clarke, R., "Hearing in *Cetacea,*" *Nature,* **161,** 979–980 (1948).
Cole, H. I., "Identification of Ambergris," *Phil. J. Sci.,* **20,** 105–109 (1922).
Geiling, E. M. K., and Oldham, F. K., "The Site of Formation of the Posterior Lobe Hormones," *Trans. Assoc. Am. Physicians,* **52,** 132 (1937). Reprint, 8.
Geiling, E. M. K., and Robbins, L. L., "The Posterior Lobe of the Pituitary Gland of the Whale; and Pituitrin and Its Fractions, Pitressin and Pitocin," *Proc. Assoc. Research Nervous and Mental Disease,* **17,** 437–462 (1936).
Geiling, E. M. K., Tarr, A. D., and Tarr, L. N., "The Hypophysis Cerebri of the Finback (*Balaenoptera physalus*) and Sperm (*Physeter megalocephalus*) Whale," *Bull. Johns Hopkins Hosp.,* **57,** No. 3, 123–142 (1935).
Gill, A. H., and Tucker, C. M., "The Composition of Porpoise Jaw Oil," *Oil and Fat Ind.,* **7,** No. 3, 101–102 (1930).
Grierson, J., "Air Whaler," New York, MacDonald and Co., 1949.
Haslewood, G. A. D., and Wootton, V., "Bile Acids of the Whale," *Nature,* **161,** 356 (1948).
Hasslauer, V., "Ambergris in Perfume Extracts," *Drug and Cosm. Ind.,* **61,** 458–460, 555–557 (1947). Reprinted in U. S. Fish and Wildlife Service, *Fishery Leaflet,* **281** (1948).
Heyerdahl, E., "On the Treatment of the Whale," *Norwegian Whaling Gas., Sandefjord,* **27,** No. 8, 339–359, No. 9, 392–407, No. 10, 440–447, 458 (1938).
Hilditch, T. P., "The Chemical Constitution of Natural Fats and Oils," London, Chapman and Hall Ltd., 1947.
Hilditch, T. P., and Lovern, J. A., "The Head and Blubber Oils of the Sperm Whale, I. Quantitative Determinations of the Mixed Fatty Acids Present," *J. Soc. Chem. Ind.,* **47,** 105T–111T (1928).
Hilditch, T. P., and Lovern, J. A., "Investigations of Some of the Component Wax Esters and the General Structure of the Oils. II," *Ibid.,* **48,** 359T–365T (1929).
Hilditch, T. P., and Lovern, J. A., "Quantitative Determinations of the Higher Fatty Alcohols Present. III." *Ibid.,* **48,** 365T–368T (1929a).
Hilditch, T. P., and Maddison, L., "The Mixed Unsaturated Glycerides of Liquid Fats. IV. Low-Temperature Crystallization of Whale Oil," *J. Soc. Chem. Ind.,* **61,** No. 11, 169–172 (1942).

Hilditch, T. P., and Terleski, J. T., "The Component Acids and Glycerides of Partly-Hydrogenated Marine Animal Oils. II. Antarctic Whale Oil," *J. Soc. Chem. Ind.*, **56**, 315T–322T (1937).

Ingram, M., "Norwegian Whalemeat Production," *Food Mfgr.*, **23**, No. 1, 15–22 (1948).

International Convention for the Regulation of Whaling of 1946, Message from the President of the United States. . . . 2 Dec. 1946 . . . Washington, D. C. [U. S.] Senate, Executive L, 80th Congress, 1st Sess., 8 April (1947).

International Whaling Statistics, "Ed. Comm. Whaling Statistics," *Det Norske Hvalrads Statistiske Publikasjoner*, 1–17, 1930 to date.

Jacobsen, A. P., "Endocrinological Studies in the Blue Whale," Hvalradets Skrifter, Det Norske Viden. akad. Oslo, No. 24, 1–84 (1941).

Jacobsen, I. A., "Whale Meat—Norway Expands Its Production," Off. Foreign Agr. Relations, U. S. Dept. Agr., *Foreign Agric.*, **13**, No. 1, 21–22 (1949).

Klem, A., "Studies in the Biochemistry of Whale Oils," Hvalradets Skrifter, Sci. Results Marine Biol. Research, Oslo, No. 11, Contributions to the Study of Whale Oils, 49–108 (1935).

Leighton, A. H., "The Twilight of the Indian Porpoise Hunters," *Nat. Hist.*, **40**, No. 1, 410–416, 458 (1937).

Lillie, H. B., "Whaling and Its Antarctic Problems Today," *Canadian Geog. J.*, **38**, No. 3, 105–113 (1949).

Lovern, J. A., "Fat Metabolism in Fishes and Cetaceans. III. Selective Formation of Fat Deposits," *Biochem. J.*, **28**, 394–401 (1934).

Lund, J., "Whale Oil and Whale Tribes," *Oil and Soap*, **13**, No. 6, 148–150 (1936).

Marcelet, H., "A Study of the Oil Extracted from the Head of the Dolphin (*Delphinus delphis* Lin.)," *Comp. rend. acad. sci.*, **182**, 1416–1417 (1926).

Milligan, C. H., Knuth, C. A., and Richardson, A. S., "The Composition of Whale Oil," *J. Am. Chem. Soc.*, **46**, 157–166 (1924).

Murphy, R. C., "Floating Gold," *Nat. Hist.*, **33**, No. 2, 117–130, No. 3, 303–310 (1933).

Ney, P. W., and Tarr, H. L. A., "Animal Protein Factor in Fish Products," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **73**, 37–39 (1949).

Okuda, Y., Okimoto, T., and Yada, T., "Hydrolysis of the Muscle-Proteins of the Whale and the Cod," *J. Col. Agr. Tokyo*, **7**, No. 1, 29–37 (1919).

Scheffer, V. B., "The Dall Porpoise, *Phocoenoides dalli, in Alaska.*" J. Mamm., **30**, 116–121 (1949).

Slipjer, E. J., "On the Thickness of the Layer of Blubber in Antarctic Blue and Fin Whales. I," *Proc. Kon. Nederl. Akad. Wetensch.*, **51**, No. 8, 1033–1045; II. No. 9, 1114–1124; III. No. 10, 1310–1316 (1948).

Smith, W. G., Co., "Advertising Material on Sperm Oils," Cleveland, Werner Smith Division of Archer-Daniels-Midland Co., 1949.

Stevenson, C. H., "Aquatic Products in Art and Industries. Fish Oils, Fats, and Waxes. Fertilizers from Aquatic Products," Rep. Commissioner, *U. S. Comm. Fish and Fisheries*, Pt. 28, for year ending 30 June 1902, 177–279, Pls. 10–25 (1904a).

Sudzuki, M., "Investigations Concerning Whales. VIII. Concerning Blood," *Tohoku J. Exper. Med.*, **5**, 419–427 (1924).

Sunderland, P. A., "Analysis of Pacific Coast Porpoise Oils," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **14**, 14–15 (1932).

Swain, L. A., "Whale Liver Oil," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **73**, 40 (1949).

Tomilin, A. G., "Le *Hyperoodon rostratus* and Small Balaenopts," *Bull. Soc. Nature, Sec. Biol., Moscow*, **47**, 210–217 (1938).

Toyama, Y., and Tsuchiya, T., "Highly Unsaturated C_{24} Acids in Herring, Cod Liver, Pilot Whale and Aburazame Liver Oils," *J. Soc. Chem. Ind. Japan*, **37**, Suppl. binding 530–534 (1934).

Toyama, Y., and Uozaki, K., "Blubber Oils of Sei-Whale, Fin Whale and Humpback Whale," *J. Soc. Chem. Ind.*, **40**, 398B–402B (1937).

Tsujimoto, M., and Koyanagi, H., "Distillation of Pilot Whale Oil Under Reduced Pressure," *J. Soc. Chem. Ind. Japan*, **40**, Suppl. binding 272–274 (1937).

Turrentine, J. W., "Utilization of the Fish Waste of the Pacific Coast for the Manufacture of Fertilizer." U. S. Dept. Agric., *Bull.*, 150, 71, Pls. 6, Tabs. 16 (1915).

Tveraaen, I., "Chemical Analysis of Samples of Blue Whale Oils," *Hvalradets Skrifter, Sci. Results Marine Biol. Research*, Oslo, No. 11, Contributions to the Study of Whale Oils, 1–48 (1935).

Vals, J., "The Hypophysis of the Blue Whale (*Balaenoptera musculus* L.). Macroscopical and Microscopical Anatomy and Hormone Content," *Hvalradets Skrifter, Sci. Results Marine Biol. Research*, Oslo, No. 16, 1–30 (1938).

Vladykov, Vladim-D., "Studies of Aquatic Mammals. III. Capture, Biology, and Economic Value of the White or Beluga Whale (*Delphinopterus leucas*) of the St. Lawrence River and Gulf," *Contr. l'Inst. Biol.*, Univ. Montreal, **15** (1944).

Weidlein, E. R., "Epinephrin from the Whale," *Ind. Eng. Chem.*, **4**, No. 9, 636–645, 5 Figs. (1912).

Williamson, K., "The Economic and Ethnological Importance of the Caaing Whale (*Globicepnala melaena Traill*) in the Faeroe Islands," *North Western Naturalist*, **20**, Nos. 3–4, 118–136 (1945).

Wislocki, G. B., and Geiling, E. M. K., "The Anatomy of the Hypophysis of Whales," *Anat. Rec.*, Phila., **66**, No. 1, 17–36 (1936).

CHAPTER 34

Seal Fisheries

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Introduction

Seal fisheries are world-wide; their purpose is the capture and utilization of fur seals and hair seals. Sea lions, sea elephants, and walrus are sought to a lesser extent. Many species have been brought perilously close to extinction because of the high value of the fur, leather, and oil products of the fishery in world commerce. Others continue in abundance as a result of international agreements and other protective regulations.

All the animals upon which this fishery depends belong to the order *Pinnipedia*, and are further classified into three families: (1) *Otariidae*, the eared seals or fur seals, and sea lions; (2) *Phocidae*, the true seals or hair seals, and sea elephants or elephant seals; and (3) *Odobenidae*, walrus. Although members of these families are essentially aquatic mammals, the hair seals are the most highly specialized for life in the water. Their necks are so short that the head can scarcely be raised; there are no external ears; and the posterior limbs are adapted for swimming to such an extent that these animals move with difficulty on land. In contrast, fur seals and sea lions can move with great rapidity on land, where they are almost as much at home as in the sea.

Fur Seals

The fur seals of the world belong to two distinct groups or genera, one of which is widely distributed throughout the Southern Hemisphere, while the other is confined to waters of the North Pacific. Fur seals belonging to the genus *Arctocephalus* were formerly found in large numbers along the coasts of South America, South Africa, Australia, New Zealand, and on many of the Antarctic islands. Only one species of this genus, the Guadalupe fur seal, is found north of the equator. It was once abundant on the islands along the coast of southern and Lower California; only a few animals still remain. The second group, belonging to the genus *Callorhinus*, occurs on both sides of the North Pacific, and accounts for about 90 per cent of all fur seals in the world. Fur seals are not found in the North Atlantic.

By far the largest and most important herd of fur seals in the world is the Alaska herd, which has its breeding grounds on the Pribilof Islands in the Bering Sea. Here more than 80 per cent of the fur seals of the world gather every year for 4 to 6 months, take up their only terrestrial life, give birth to their young, breed, and yield a part of their number to meet the demands of a strong world

fur market. Other herds of commercial importance resort to the Commander Islands off the Siberian coast, controlled by Russia; Robben Island and the Kuriles, formerly belonging to Japan, but now administered by Russia; Lobos Island belonging to Uruguay; and to the coastal area and adjacent islands in the vicinity of Cape of Good Hope, South Africa. Remnants of once large herds are still to be found on many of the small islands in the South Atlantic, the Crozet Isles in the

(Courtesy U. S. Fish and Wildlife Service)

FIG. 34–1. Fur seal harems at the Polovina Rookery, St. Paul Island, Alaska.

South Indian Ocean, Guadeloupe in the West Indies, and the Galapagos Islands in the Pacific. Tasmania, New Zealand, and Australia still have fur-seal colonies, but these have been so reduced in size that the number of skins now obtained is extremely small.

Southern Hemisphere. Fur seals of the Southern Hemisphere were the first to be seriously exploited. Beginning about the end of the eighteenth century fur-seal hunting grew rapidly in importance, and early in the nineteenth century it assumed gigantic proportions. Sealing first began at the Falkland Islands about 1784, and according to the old accounts "millions were taken during the next fifteen years." Fur seals were present in such numbers that there are records of "eight or nine hundred in a day" being killed with clubs on a single small islet. There are now no fur seals on the Falkland Islands, and they are reported to have become extinct about 1800.

Sealing voyages were made to the west coast of South Africa as early as 1790. The sealing fleet extended its range to include first the South Georgian rookeries, then successively those off the coast of Chile, Patagonia, Australia, the Antipodes, Crozet and Prince Edward Islands, the South Shetlands, Kerguelen Island, and others of lesser importance. There were approximately 60 vessels in the sealing fleet in 1801. The United States, Great Britain, Portugal, Germany, Russia, and

France participated in this enterprise. The fur-seal skins obtained were taken mostly to the Canton market where, in exchange for teas and silks, they brought the comparatively low price of 50 cents to $5.00 each. The fur was removed and only the hides were used, chiefly in the manufacture of leather luggage.

The sealing business was a profitable one, however, and this stimulated indiscriminate slaughter. One after another of the seal rookeries was discovered and decimated. Every seal that could be obtained was killed regardless of sex or age. So vigorously was sealing prosecuted that when the South Shetland rookeries were discovered in 1820 their immense wealth of seal life was nearly exterminated in a single season. There is a record of one vessel taking 57,000 fur-seal skins in one season's operations. The period of prosperity was short-lived, and fur seals are now present in the Southern Hemisphere in significant numbers only on the South African coast and on Lobos Island off the coast of Uruguay, where they are protected and utilized on a management basis. Fur seals elsewhere south of the equator owe their existence to the inaccessibility of the rocky shores they inhabit, which offer partial protection against human depredation.

Northern Hemisphere. In the North Pacific the Pribilof Islands were discovered by the Russian navigator Gerassim Pribilof in 1786, and the slaughter of fur seals began there immediately, following the same destructive pattern pursued in the Southern Hemisphere. At the time of discovery it was estimated that this herd contained at least 5,000,000 fur seals. About 2,000,000 fur seals were killed in the 50 years immediately following the discovery of the islands. By 1835 the Russian management had grown apprehensive of the future of the herd, and consequently imposed restrictions on shore killings on the Pribilofs. These restrictions were applied soon enough, and the herd responded to the more favorable conditions. In 1867, when these islands were acquired by the United States in the Alaska purchase, it is estimated that there were 3,000,000 fur seals in the herd.

During the first 40 years of ownership by the United States the sealing privilege on the Pribilofs was leased to private companies, and more than 2,300,000 fur-seal skins were taken, for which about $9,500,000 was paid into the United States Treasury. Such operations on shore were carefully regulated; but in 1879 and thereafter, until stopped by the treaty of 1911, pelagic sealing (the killing of seals at sea) took a heavy and damaging toll, and the herd suffered a serious decline. The Indians of the northwest coast from time immemorial followed the custom of spearing fur seals from their canoes as the herd passed along their shores from February to May. The number of animals so taken, primarily for food, was small and probably never exceeded a few thousand. In 1879, however, schooners engaged in this fishery. They were fitted out to transport hunters and canoes to the sealing grounds and to care for them there. These schooners, averaging 70 tons, with sealing canoes and hunters on board, sailed chiefly from Victoria, British Columbia, but others based at Pacific Coast ports from San Diego to Seattle. Pelagic sealing commenced off the California Coast late in December, and the migrating Pribilof herd was followed northward into the Bering Sea, where operations continued until September. A less important but equally intense and damaging pelagic sealing industry was dependent upon the Japanese and Russian fur-seal herds. The sealing grounds along the Asiatic Coast extended from the latitude of Yokohama to the Commander Islands in the Bering Sea, and the season was from March to September.

The rise of pelagic sealing was rapid. From one vessel in 1879 the sealing fleet expanded to 122 vessels in 1891. The pelagic sealing fleet reached its peak in 1894, when the ocean catch from the Pribilof herd totaled 143,000 animals. Thereafter, the pelagic catch declined, and in 1902 did not exceed 15,000 seals.

Sealing on land could be controlled and the animals to be killed were selected with respect to sex and age. At sea, however, all animals were targets. The result was the loss of many injured animals, and many that were killed outright could not be reached. In all cases the killing of female seals at sea meant the destruction of an unborn pup or of a pup left on shore to starve. The pelagic sealing catch, therefore, did not reflect accurately the drain on the herd.

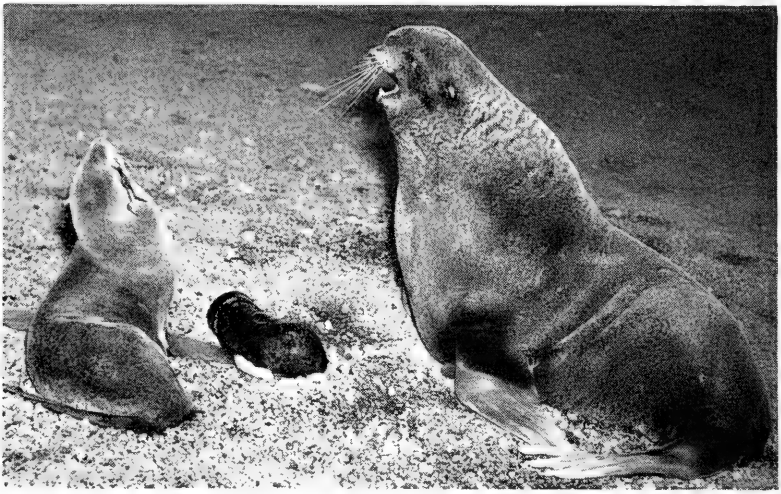
Though pelagic sealing was an extremely wasteful process, nothing could be done about it because it was carried on in waters beyond the control of the countries possessing the rookeries. An effort was made by the United States to prevent sealing in the Bering Sea. Acting upon the precedent established by Russia in the Ukase of 1821 the United States seized and confiscated a number of the sealing vessels that entered the Bering Sea. A lengthy controversy with Great Britain ensued since the pelagic fleet was very largely of Canadian registry. In 1892 the entire matter was remanded to a tribunal of arbitration for settlement of the question of jurisdiction over fur seals on the high seas, and also for recommendation of measures for the protection of fur seals. The tribunal of arbitration met in Paris in 1893 and denied the United States authority to exercise jurisdiction over Pribilof Islands' fur seals when such animals were more than 3 miles from shore. Regulations were formulated, the essential features of which were the establishment of a closed zone of 60 miles about the islands in the Bering Sea and a closed season from May 1 to August 1, within which all pelagic sealing was prohibited. These regulations were inadequate and the Pribilof herd continued to decline.

By 1910 this once great herd numbered only 130,000 animals. Pelagic sealing as well as land killing was unprofitable. Timely and concerted action by conservationists of the United States, Great Britain, Japan, and Russia finally succeeded in getting their countries to accept the terms of the fur-seal treaty of 1911. Under the terms of this convention the nationals of each of the treaty powers were prohibited from engaging in pelagic sealing in the waters of the Pacific Ocean north of the thirtieth parallel of north latitude, including the Seas of Bering, Kamchatka, Okhotsk, and Japan. Exception was made for aborigines using primitive methods in treaty waters. Management of fur seals on land was left to the country having jurisdiction over the rookery area, and provision was made for Japan and Canada each to receive 15 per cent of the land killings by the United States and Russia, and for the United States, Russia, and Canada to each receive 10 per cent of the land killings on Japanese seal islands. Great Britain had no shores frequented by fur seals within the protected area. This convention, as drawn, was to remain in effect for 15 years and thereafter, until one of the treaty powers should give one year's notice of desire to terminate it. Japan gave notice of abrogation on October 23, 1940, and the treaty was terminated on October 23, 1941.

A provisional fur-seal agreement was entered into by the United States and the Dominion of Canada on December 19, 1942, and a new Alaska fur-seal law, giving effect to the provisional agreement, was approved on February 26, 1944. With enforcing legislation by the Canadian Government the agreement provides, among other things, for continuation of the prohibition on pelagic sealing, and for

delivery to Canada of 20 per cent of the skins taken on the Pribilof Islands, the remainder to be retained by the United States.

The international cooperation afforded by the treaty of 1911 and the provisional agreement of 1942 has resulted in the most outstanding of all accomplishments in the conservation of wildlife. Since 1911 the herd has steadily increased. In this



(Courtesy U. S. Fish and Wildlife Service)

FIG. 34–2. A small family of fur seals, St. Paul Island, Alaska.

period more than 1,500,000 seals have been killed for their fur. This almost phenomenal growth was possible through careful management, taking into consideration all phases of the fur seal's natural history. Were it not for the polygamous nature of fur seals, the birth of both sexes in equal numbers, and the early maturity of the females, the herd would still be of almost insignificant size.

The convention of 1911, during the 30 years it was in effect, afforded protection to the Robben Island herd, then under the jurisdiction of Japan, and the Commander Islands herd belonging to Russia. In 1945 the Robben Island herd was estimated to contain 60,000 seals and the Commander Islands herd, 56,000. Prior to World War II land killings by Japanese authorities on Robben Island totalled 2,000 to 3,000 animals annually.

Natural History. The Alaska fur-seal herd spends 4 to 6 months during the summer and fall of each year on the Pribilof Islands and in adjacent waters. The remainder of the time is spent at sea; seldom do they appear ashore at any other place. The first animals to arrive at the Pribilofs in the spring are the mature bulls. These take up strategic positions along the beach where they await the arrival of the cows. The younger, less experienced bulls are forced to take less advantageous positions at the rear of the rookery areas. During this period there is constant bellowing of competing animals, but there is little real fighting. The cows commence to arrive early in June and harems of 75 to 100 cows for each bull are formed. Soon after coming ashore each cow gives birth to one pup weighing about 12 pounds. Breeding takes place soon after the young are born, the period

TABLE 159. COMPUTATION OF PRIBILOF ISLANDS FUR-SEAL HERD AND NUMBER OF SEALSKINS TAKEN BY THE GOVERNMENT, 1910–1949.[1]

Year	Sealskins obtained	Animals in herd	Year	Sealskins obtained	Animals in herd
1910	12,964	132,279	1931	49,524	1,127,082
1911	12,138	123,600	1932	49,336	1,219,961
1912	3,191	215,738	1933	54,550	1,318,568
1913	2,406	268,305	1934	53,470	1,430,418
1914	2,735	294,687	1935	57,296	1,550,913
1915	3,947	363,872	1936	52,446	1,689,743
1916	6,468	417,281	1937	55,180	1,839,119
1917	8,170	468,692	1938	58,364	1,872,438
1918	34,890	496,432	1939	60,473	2,020,774
1919	27,821	524,235	1940	65,263	2,185,136
1920	26,648	552,718	1941	95,013	2,338,312
1921	23,681	581,443	1942	150	2,585,397
1922	31,156	604,962	1943	117,164	2,720,780
1923	15,920	653,008	1944	47,652	2,945,663
1924	17,219	697,158	1945	76,964	3,155,268
1925	19,860	723,050	1946	64,523	3,386,008
1926	22,131	761,281	1947	61,447	3,613,653
1927	24,942	808,870	1948	70,142	3,837,131
1928	31,099	871,513	1949	70,891	
1929	40,068	971,527			
1930	42,500	1,045,101			

[1] This computation is based upon actual count of harem, idle, and surplus bulls, number of animals killed, and mortality of each age group as determined when the herd was small. Since animal populations seldom increase at a constant rate, the validity of this computation since 1940 is questioned, and information on this subject is being sought in aerial photographic surveys and by other means.

Source: U. S. Fish and Wildlife Service.

of gestation being about one year. The females are mature in their second year and give birth to their first young when 3 years old. Males mature when 6 or 7 years old. Both males and females have a life span of approximately 15 years. At maturity a fur-seal bull weighs about 500 pounds, and a cow 90 pounds. Pups and cows leave the Pribilofs in November, followed later by the other seals as winter approaches. There is a general dispersal of these animals in the ocean, some going as far south as the latitude of southern California, while others remain in the Gulf of Alaska. It is unusual that more than a handful of fur seals are seen together at any time during the winter months at sea. The "herd instinct" evidently is not strong at this time.

As might be expected fur seals feed on whatever is readily available. On the northward migration along the British Columbia coast herring is important in their diet, but many almost unknown species of fish having no commercial value are eaten also. The principal food throughout their range, and one for which there seems to be a decided preference, is squid. There is no evidence that the Pribilof fur-seal herd is a menace to any existing commercial fishery.

Because of the polygamous habits of the fur seal and the fact that the sexes

are in equal numbers at birth, there are many males unneeded to maintain the herd and provide for its continued growth. Instead of permitting the normal increase of male animals, therefore, this sex is maintained at the most desirable ratio by killing the surplus males for their fur. The fur is best on the 3-year-olds, and the males of this age group comprise the bulk of the Pribilof take. The bachelors segregate themselves from other seals on shore, and the job of killing the right

(*Courtesy Fouke Fur Co.*)

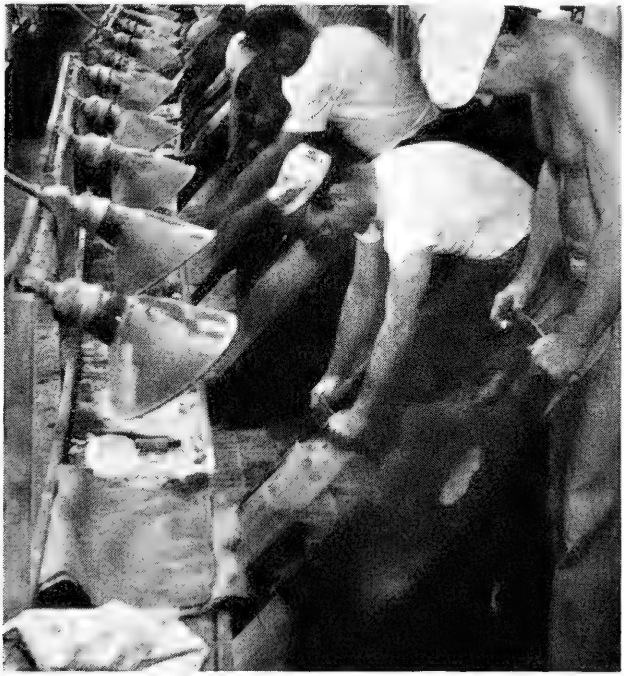
Fig. 34–3. The sealskins are heavily salted and packed in barrels for transporting to the processing plant.

animals is thus made easy. A proper number of 3-year-old males are reserved from killing for future breeding stock. No female is ever purposely killed.

Sealing Methods. At the Pribilof Islands most of the sealskins are taken in June and July. Daily drives are made of the hauling grounds where the immature males are ashore. Gangs of men running along the beach between the seals and the water prevent their escape and the animals are slowly driven inland to killing fields. During the progress of the drive animals other than 3-year-old males are eliminated and allowed to return to the water. The killable animals are then divided into small groups of 10 to 15 seals, and each is dispatched by a sharp blow on the head, followed immediately by a knife thrust in the heart, in much the same manner as a slaughterhouse operation.

Some years ago each pelt was removed by skinning entirely with a knife. Now a cut is made with a knife up the belly, around the flippers, and across the head at eye level, and the skin is loosened from the head, after which it is stripped from

the carcass with specially designed tongs. This method leaves most of the blubber adhering to the pelt, whereas the method of knife-skinning left very little blubber on the skin. In the stripping method the skins are taken from the killing field to a tank house where they are washed and submerged in sea water until the blubber hardens and can be removed with a beaming knife. The skins, free of blubber, are then cured in salt, barreled, and made ready for shipment. By using the pres-



(Courtesy Fouke Fur Co.)

FIG. 34–4. Removal of the guard hair, exposing the soft luxurious under fur of the sealskins.

ent stripping method it is possible to handle as many as 5,000 skins a day, use less skilled help, and have fewer cut and scarred skins than was possible in the knife-skinning method.

The cured skins are shipped from the Islands to the Fouke Fur Company, St. Louis, Missouri, which has the contract for dressing, dyeing, and selling all United States Government sealskins. When received, they are carefully inspected for defects or imperfections which would make them unfit for processing, and are then graded as to size and quality. Next, they are washed thoroughly, and each is laced in an oval iron hoop where it is stretched to its proper size and shape and prepared for removal of the guard hair by hanging in a heated room, or cockle, where both temperature and humidity are carefully controlled. Here the guard hair is loosened in its follicles and can be removed without damage to the fine under fur. This is one of the most delicate steps in the processing of the skins. In unhairing, the skins are laid over beaming boards and the guard hair is pulled

out with a downward scraping movement of a 2-handled curved knife, the edge of which is just dull enough to prevent cutting the hair or fur.

After unhairing, the skins are tanned or "leathered." They are given a preliminary treatment in which a slight amount of moisture is left in the pelt. Seal oil, which as mentioned above, is extracted from the seal's own blubber is then painted on the flesh side, and the skins are run in a "mill." The action of this mill is similar to the old method in which men tread on the sealskins in their bare feet, but the machine is much more effective and uniform in its action and very much more rapid. The tannage is produced entirely and solely by the action between the seal oil and the hide fiber, no so-called "chemicals" being used. This process gives a true oil tannage, commonly known as "chamois tannage."

During the tanning process the fur naturally becomes very greasy; and before dyeing is attempted this grease or oil must be removed. This is accomplished by running the sealskins several times in specially constructed mills with hardwood sawdust. In these mills the skins and sawdust are together kicked back and forth; the sawdust, forced down through the fur to the grain, absorbs by capillary attraction the grease held by the fur. Between mill runs the dirty sawdust is shaken out of the skins by tumbling them in steel wire "cages" (similar to some methods of carpet cleaning). This allows clean, fresh sawdust to get down into the fur.

Sawdust is a very useful and necessary material in the dressing and dyeing of sealskins. It is used probably 25 or 30 times during the process, and special kinds of dust are most suitable for each different operation. No other material that has been tried, such as cornmeal, etc., has proved as satisfactory. For sealskins and other furs, however, only the best grades of hardwood dust are suitable. Dust from soft, resinous wood would spoil the furs.

The skins are then dyed. This operation requires considerable skill and experience as it is entirely done by brushing the dye on the fur rather than by immersing the skins in a dye bath. The dyeing operation is divided into three main steps. In the first step the fur is given what is called a "killing"; this is really a mordant. In the next operation a vegetable black is applied to the upper half of the fur. In the last operation the whole length of the fur from the tips to the roots is treated with a vegetable color of rich chocolate brown. It is this method that produces half brown and half black fur which has been imitated in substitutes such as Hudson seal. More than 2 dozen applications of dye are given to the fur.

All fur-seal skins were formerly dyed black, but in response to the market demand a satisfactory brown dye was developed and was first offered to the trade in 1924. Subsequently other shades of brown have replaced the one originally used. At present, in addition to black, two shades of brown are available: Safari brown, which has been popular since its first introduction in 1934, and Matara brown, a neutral shade, offered for the first time in 1939.

As the pelts are still too thick to be used by the furrier, they are made thinner by passing them through shaving machines—large cylindrical drums covered with an abrasive and revolving rapidly. The surplus pelt is actually buffed off. During the dyeing process the pelt itself is not stained through with the dye, but merely picks up a surface coat of black. In the buffing operation this black surface is removed and a white or rather light yellow chamois leather is produced.

The unhairing process removes only the coarse hair which is longer than the fur. Practically every sealskin, however, has more or less growth of stubby hair

which is shorter than the fur and must be removed in some other way. This is done after the pelt is reduced to the proper thickness by an operation called "machining." The sealskin is passed several times through a machine consisting of an ingenious arrangement of air blasts, combs, and knives. The pelt is bent sharply over a dull knife edge and the downy fur is blown down or parted by the air blast. The short guard hairs, because of their comparative stiffness, are not

(*Courtesy Fouke Fur Co.*)

Fig. 34–5. Bench dyeing of the fur sealskins.

blown down by the blast, but stick up. While blown down, the soft fur is caught and held in place by combs and the short stiff hairs are then clipped off almost at their roots by knives. This operation improves to a marked degree the smooth, soft appearance of the fur.

In the final operation, called "finishing," the pelt is worked into an extremely soft and pliable condition, and the fur is "set" so that all the strands lie parallel. The skins are then ready for sale and can be worked directly into garments.

It should be mentioned that during the various processes the skins are dried several times and in other ways exposed to increased temperature, but in all these cases very careful control of the operation is necessary as the skins must never be exposed to a temperature above 120° F (48.9° C) as this results in disintegration of the pelt.

In the dressing and dyeing of fur-seal skins great care is taken to assure a superfine product. More than 100 distinct processes are involved in treating each skin, and the minimum time required is approximately 90 days.

By-Products. A reduction plant is operated on St. Paul Island, where about 80 per cent of the Pribilof fur seals are killed. The annual yield is about 350 tons of meal and 17,000 gallons of oil. On the basis of past production records, each fur seal taken yields about 4.25 pounds of blubber oil, 2.2 pounds of carcass oil, and 12.6 pounds of meal.

The carcasses are all delivered to the plant immediately after the skins have been removed, and are never held more than one day before processing. Upon arrival, they are dumped into a large hopper, from which a conveyor carries them to the hog, where they are chopped into small pieces to promote quicker, more uniform rendering. These pieces are carried by another conveyer to steam-jacketed center-feed type melters, which are suitable for dry rendering at atmospheric pressure, rendering under internal pressure, rendering under vacuum, or any combination of the three. The dry-rendering process has given the best results and is currently being used. A melter load is 200 carcasses. Melters are unloaded into large pans

TABLE 160.

Fur-Seal Carcass Oil

	Per cent
Free fatty acids (as oleic)	5.85
Moisture	0.80
Insoluble matter	5.66
Iodine number (Wijs)	132.5
Stearin at 70° F (21.1° C)	2.18
Unsaponifiable matter	2.06
Titer	65.7° F (18.7° C)
Lovibond color using a ¼″ Column:	
Yellow	55
Red	15.4

Fur-Seal Blubber Oil

Free fatty acids (as oleic)	1.05
Moisture	0.34
Insoluble matter	0.05
Iodine number (Wijs)	132.5
Stearin at 70° F (21.1° C)	1.04
Unsaponifiable matter	0.49
Titer	70.2° F (21.2° C)
Lovibond color using a 1″ Column:	
Yellow	20
Red	3.5

Fur-Seal Meal

Moisture	5.49
Fiber	0.13
Protein ($N \times 6.25$)	63.50
Ash	14.66
Fat	14.89

and the meal is automatically fed to a mechanical press or expeller and over a magnetized belt. This produces from 800 to 1,000 pounds of pressed cracklings per hour. From the expeller the dried meal goes first to a cooling room, then to a hammer mill where it is pulverized, after which it is sacked. The carcass oil is pumped from the expeller to settling tanks prior to barreling. Blubber is rendered separately from the carcasses, and blubber oil usually commands a higher market price than carcass oil. The laboratory analyses of fur-seal oil and fur-seal meal produced in 1949 are shown in Table 160 (p. 726).

Hair Seals

Hair seals are widely distributed, but occur in sufficient numbers to support important fisheries in only a relatively few well-defined localities. They include the waters along the west coast of Greenland, the coasts of Newfoundland, Labrador, and the Gulf of St. Lawrence, Jan Mayen Island and adjacent waters, Novaya Zemlya Island and adjacent waters, and the White Sea. The Caspian Sea also supports a hair-seal fishery. Small isolated groups of hair seals, of local importance only, are found along both coasts of the United States, around the British Isles, among the islands of the south seas, along both coasts of South America, and in Alaskan and Siberian waters. The species of chief importance commercially are the harp seal (*Phoea groenlandica*), the hood seal (*Cystophora cristata*), the harbor seal (*P. vitulina*), and the Caspian seal (*P. caspica*). The ringed seal (*P. faetida*) and the gray seal (*Halichaerus grypus*) also are taken. The harp seal, which gets its name from dark markings on its back which resemble a harp, is the species of greatest commercial importance, both in number of animals captured and value. In years of normal operation the number of harps killed has equalled or exceeded that of all other species combined. It is the seal on which the Newfoundland, Greenland, and Arctic fisheries depend.

The once extensive hair-seal fishery of the South Atlantic, South Pacific, and Antarctic regions was primarily for the capture and utilization of the elephant seal or sea elephant, although some sea lions were also taken. This fishery, prosecuted in conjunction with whaling and fur sealing, was chiefly for the oil. Elephant seals were abundant on many of the islands off the southern coasts of South America, Patagonia, the Falkland Islands, the South Shetlands, the South Georgian Islands, and Crozet and Kerguelen Islands, where important fur-seal colonies existed. The slaughter of these animals in the early years of sealing was uncontrolled, and the inevitable result has been extermination in many places. This fishery now has been virtually abandoned, and where this species has been protected, it is showing evidence of recovery.

The Newfoundland hair-seal fishery is the most important in the world. Because of economic difficulties besetting the industry as well as decimation of the seal herds this fishery has shown evidence of failing. In 1855, 400 vessels and 13,000 men were engaged in this fishery and took a total of more than half a million seals. Prior to that time there had been a gradual change in the method of sealing, from exclusively shore operations employing nets to ice skiffs, small schooners, brigs, brigantines, and barks, successively. After 1855 the decline in sailing vessels commenced, and 25 years later they were a thing of the past. Steamers appeared in the fishery in 1863, and by 1906, 25 steamers were engaged, furnishing employment to more than 4,000 men. The number since then has gradually declined, and

in 1938 there were only 8 steamers and 1,459 men engaged in sealing. Several disasters in which 2 sealing steamers were lost in 1940 and 1 in 1943, with diversion of others to emergency duties during World War II, brought a further decline to this industry, and in 1946 operations were limited to 1 steamer and 4 small motor vessels of less than 200 tons each. By 1949, however, there were 15 vessels in the Newfoundland fishery, ranging from 68 to 950 tons in size, thus indicating a prompt recovery from war-time conditions.

The catch of seals through the years has followed a downward trend, paralleling that of ships and men employed. Until about 1860 the average annual take of seals was in excess of 500,000. From 1860 until the early part of the twentieth century the catch averaged well above 200,000 annually, but after World War I it dropped to an average of less than 125,000. The catches in 1941, 1942, and 1944 were insignificant; the sealing fleet did not operate in 1943 or 1945. With 15 vessels operating in 1949 the total take was 135,000 seals, valued at about half a million dollars.

The principal species taken in the Newfoundland fishery is the harp seal. Of the 1949 take of 135,000 seals 116,000 were harps. Hoods are taken in considerable numbers and are next in importance. These animals follow fairly definite routes of migration. Late in October they leave the Arctic ice and migrate south as far as the great Ocean Banks off Cape Race. In this migration the harps appear to originate in the vicinity of Hudson Bay, and the hoods come from the Greenland shores, the two species meeting off the Labrador coast. Returning north they again mount the ice in the neighborhood of the Straits of Belle Isle about the end of February. At this time the young are born, and about a month later the hunt begins. Voyages commence early in March. The vessels cruise in a northerly direction, usually first locating the seals in the vicinity of Funks Islands, between 50 and 100 miles off the northeastern coast of Newfoundland. The seals, congregated in great numbers, are rounded up, prevented from returning to open water, and clubbed over the head. When all the seals are killed, the hunters remove the skins with the adhering layers of blubber and drag them back to be packed into the hold of the ship. When a full cargo is obtained, the vessel returns to its home port, where the skins are unloaded, the blubber removed, and the hides prepared for manufacture into leather (Chapter 25).

Hair seals do not have the fine under-fur that characterizes fur seals, and comparatively little use is made of these skins in clothing. The oil extracted from the blubber is used as a lubricant in the leather industry and in soap manufacture.

The hair-seal fishery of Jan Mayen Island ranks second to that of Newfoundland, and was prosecuted by vessels from England, Norway, and Germany. The catch never equalled that of Newfoundland, and signs of depletion developed early. Despite attempts at regulation, this fishery was seriously depleted by the end of the last century. Substantial catches are made annually at Novaya Zemlya and in the White and Caspian Seas. Many hair seals are taken annually along the Alaskan and Siberian coasts of the North Pacific and Arctic Oceans by natives for food and clothing; no commercial fishery of any consequence is carried on in these waters. Bounties are offered for destruction of the harbor seals in parts of Alaska and in some of the Pacific Coast states, where they occur in sufficient numbers to be considered a menace to the various species of food fish of commercial importance.

Sea Lions

Five species of sea lions have, at one time or another, played a part in the seal fisheries of the world. These are the California sea lion, *Zalophus californianus;* the Steller sea lion, *Eumetopias jubata;* Southern sea lion, *Otaria byronia;* Auckland sea lion, *Phocarctos hookeri;* and Gray sea lion, *Zalophus lobatus.* The California sea lion is found from San Francisco Bay to Lower California, and the Steller sea lion from San Francisco Bay north to the Bering Sea and on the Asiatic Coast as far south as Japan. The other species are found only in the Southern Hemisphere: the Auckland sea lion at the Auckland Islands, the Gray sea lion in the waters of New Zealand and Australia, and the Southern sea lion along the southern coast of South America.

All these species have been hunted for their hides and their oil. This fishery today is negligible, and in North American waters is nonexistent. California sea lions supply the trained seals of the circus and stage, and are protected from other commercial use. The Steller sea lion is protected in part of its range, and is the target of bounty hunters in other parts. In Alaskan waters from 1908 to 1949 it was accorded almost complete protection, except for local use by aborigines. The increase in numbers was so pronounced that in 1949 all restrictions on killing were removed, except in the vicinity of Bogaslof Island in the Bering Sea, but there has been no commercial interest shown in these huge marine mammals, which may attain a maximum weight of 2,000 pounds. There is a limited sea-lion fishery, the products being meal, oil, and leather, along the South American Coast, particularly Uruguay and Argentina.

Walrus

The walrus are confined to Arctic and subarctic waters, and have no representatives in the Antarctic regions. As they exist today, there are two species: Atlantic walrus, *Odobenus rosmarus;* and Pacific walrus, *Odobenus divergens.* Very similar in appearance, the differences in these two species are apparent only to the taxonomist.

Atlantic Walrus. This species is now found in Hudson Bay, Davis Strait, and the coast of Greenland. On the European Coast they are confined chiefly to Spitzbergen, Novaya Zemlya, and the smaller islands of the Arctic Ocean. These animals once ranged far south of their present habitat, but were exterminated in more accessible waters in the ruthless hunt for ivory, hides, and oil which began in the seventeenth century and accounted for thousands annually. As in the Pacific, the few remaining animals are used almost exclusively by the residents of the remote coasts where they occur.

Pacific Walrus. The Pacific walrus was formerly abundant in the Alaskan Arctic and Bering Seas as far south as the Pribilof Islands and the Alaska Peninsula; there is no evidence that their range extended south of the Aleutians. Hunted for their ivory, hides, and oil their numbers were greatly reduced by 1900. The range today extends only to the southern fringe of the Arctic ice pack, about 62 degrees north latitude, in January, and these animals remain close to the ice pack as it moves northward in the summer. They usually appear off St. Lawrence Island in May, pass King Island in early June, and soon thereafter move northward through the Bering Strait. In early July they arrive off Point Hope, and a

few weeks later reach Point Lay, where they feed on the extensive clam beds. The Pacific walrus is not found east of Point Barrow. This same species occurs off the Siberian Coast, and it is believed by some that both the old world and new world animals commingle in their migration. The herds move west and south from the Alaskan Arctic in the fall, just ahead of the ice.

The wrinkled, blotchy skin of this animal, its great bulk, tusks, and bristled, blunt nose, give it a very grotesque and formidable appearance. Walruses spend much time lying and sleeping on the ice floes, occasionally going into the water to feed on clams and other mollusks, which they dig, partly with their tusks, from beds in the shallow sea. They are strongly gregarious and assemble in large numbers, both in the water and on the ice. The young are born as they drift north on the ice floes during May and June, and breeding occurs in June and July, at which time there is much fighting among the bulls. There is a strong family instinct and the adults defend their young vigorously. Adult animals attain a weight of 2,000 to 3,000 pounds, and are known to have tusks as long as 36 inches, though the usual length is much less.

In Alaskan waters the killing of walrus is prohibited except by natives for food and clothing. As a further measure of protection the shipment of raw walrus ivory out of Alaska is prohibited. The meat, blubber, skins, and ivory of the walrus are all used by the Eskimos, and some coastal villages are virtually dependent upon these animals for their existence; without them the Eskimos of these villages would be without their principal food, material for clothing and shelter, and raw material for their basic trade of ivory carving. The annual kill of walrus by the Alaskan Eskimos is estimated at between 1,000 and 1,500 animals.

Method of Hunting. In former times walrus were taken by the natives by harpooning them from skin boats, kayaks, or lancing them on the ice; now they use high-powered rifles. Along the Alaskan Arctic Coast the hunting operations are carried out in the following manner chiefly in the spring.

The natives use a launch or whale boat, powered by an outboard motor, to tow a string of skin oomiaks out along the icepack off shore to the areas where the animals are hauled out on the ice. They locate them in spite of the almost continual fog that hangs over the ice, by listening for their roaring whistle that seems to carry for a great distance. This sounds somewhat like the distant baying of a hound. Walrus swimming in the water also lead the natives to the places where the great herds are congregated. Walrus in the water seem very wary and hard to approach, but on the ice they are easily approached. When the boats have worked their way in among the large pods of walrus hauled out on the ice, the Eskimos select a small group of the animals that are ideally situated for killing. It would be too dangerous to make a kill where several hundred are congregated, and this is avoided.

When a small group has been selected on some flat ice that is favorable for cutting them up after the kill, the natives tie up their boats and several stay behind to protect the boats from the animals in the water. The hunters make ready an oomiak, and after saying a prayer they paddle to the group of walrus. Three or 4 hunters in the bow of the boat are ready with rifles, and they do the shooting. As the boat approaches to within 15 or 20 feet of the walrus, the men talk in low tones. This talking seems to keep the herd from becoming alarmed. As the boat approaches, the animals rear themselves erect and watch.

At the signal the men in the bow open fire, aiming to hit the beasts in the neck just below the back of the head. When the shooting starts, the walrus charge into the sea and soon the ice is clear of all except the dead ones. As soon as the shooting is over the natives paddle for the ice and haul the oomiak out. One man then runs over to the walrus with a rifle and shoots those still alive to keep them from moving and slipping off the ice.

The walrus that have escaped into the water come charging around the ice, roaring and splashing. The natives wave their hands at them to scare them away. If females or young have been killed, the herd will return to the vicinity of the kill and the natives have a busy time keeping them from wrecking the boats.

The next operation is to cut them up and load the meat and blubber into the boats. The animals are cut open with axes and knives, and the skeleton is cut out of the carcass. These bones are thrown into the water. The meat and blubber that is left is cut into squares and loaded into the boats. Occasionally one is skinned when skins are desired to make rope, boats, or houses. The skins used for boat covers are split by the women. The tusks and flippers are also saved, and the intestines are sometimes used to make windows for the houses, floats, and clothing. From four to 5 walrus can be loaded into the average oomiak boats, according to the distance they have to be towed and the weather conditions.

At King Island the natives hunt walrus by getting on the ice floes and approaching them on foot. To kill walrus in the water the natives wound them by shooting them in the back to prevent sinking, and then harpoon them before shooting to kill.

It is reported that the Eskimos at Indian Point, Siberia kill walrus by going among the herds on the beach or on the ice and lancing them with spears or knives. They do not allow the use of rifles because they claim that this would drive the animals from that vicinity and they would not come ashore. It seems that shooting alarms the animals, but they take very little notice when some of their numbers are quietly killed nearby.

When the shooting method is used in hunting walrus, a few of the animals are wounded, get into the water and are lost, but the natives make every effort to harpoon them. The ones that sink often drift ashore later on and are used by the natives for dog feed and trap bait.

REFERENCES

Allen, G. M., "Extinct and Vanishing Animals of the Western Hemisphere with the Marine Species of all the Oceans," Amer. Comm. for International Wild Life Protection, *Spec. Pub.*, No. 11 (1942).

Anderson, R. M., "Mammals of the Eastern Arctic and Hudson Bay, Canada's Eastern Arctic," Dept. Interior, Ottawa, J. O. Patenaude, 67–108 (1934).

Anderson, R. M., "Mammals and Birds of the Western Arctic District, Northwest Territories, Canada's Western Northland," Dept. Mines and Resources, Ottawa, J. O. Patenaude, 97–122 (1937).

Anon., "Newfoundland's Seal Fishery—Will It Recover?," *U. S. Consular Rept.* **7** St. John's (1946).

Anthony, N. E., "To the Arctic for Walrus," *Natural History*, **29**, 50–64 (1929).

Barabash, N. D., "Pinnipeds of the Commander Islands," *Trans. Inst. Fish. and Oceanog. (U.S.S.R.)*, **3**, 223–237 (1936).

Barabash, N. D., "Mammals of the Commander Islands and the Surrounding Sea," *J. Mammalogy*, **19**, No. 4, 423–429 (1938).

Black, M. M., Rapson, W. S., Schwartz, H. M., and Van Rensburg, N. J., "South African Fish Products. Part XIX. The South African Seal Fishery," *J. Soc. Chem. Ind.*, **64**, 326–331 (1945).

Bonnot, P., "Report on Seals and Sea Lions of California," Calif. Div. of Fish and Game, *Fish Bull.*, **14** (1928).

Collins, G., "Habits of the Pacific Walrus (*Odobenus divergens*)," *J. Mammalogy*, **21**, No. 2, 138–144 (1940).

Evermann, B. W., "Why not Save the Marine Mammals of the Pacific?," *Pan-Pacific Union Bull.* (*N.S.*), **34**, 12–16 (1922).

Stenjneger, L., "Fur-seal Industry of Commander Islands, 1897–1922," Washington, Government Printing Office (1925).

CHAPTER 35

Commercial Sponges

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History

The taking of sponges for commercial purposes was first practiced in the Mediterranean, where the occurrence, properties, and uses of these interesting marine animals have been known for many centuries, as is evidenced by various references to them in the works of Homer and other authors of classic Greece. Apparently, there was an extensive and lucrative sponge trade several centuries before the Christian era, and the sponge fishery was a recognized industry, not infrequently mentioned in early Greek literature.

The fishery originated in the eastern part of the sea and was followed particularly by the Greeks of the islands of the Aegean, where there developed a race of daring and hardy divers who have never known any real rivals. They gradually extended their field of operations to the north coast of Africa and the central Mediterranean, and in more recent times to the coast of Florida and, to a minor extent, other parts of the western Atlantic. The major part of the population of a number of the islands of the Aegean Sea and contiguous waters for centuries has been composed of sponge fishers and their families.

Until 1841 the world's sponge supply was derived solely from the waters of the Mediterranean, but in that year a French sponge merchant, who had been wrecked in the Bahama Islands, was attracted by the quality of the native sponges, and shipped a sample lot to Paris. Eight years later the exports of sponges from the Bahamas were valued at about $10,000. In 1849 the first Florida sponges were shipped from Key West to New York with the hope that they might be sold. At this time the American market was supplied solely by the Mediterranean fisheries, and the venturesome cargo from Key West narrowly escaped being thrown away as worthless. Its ultimate sale, however, and a gradual recognition of the merits of these sponges and their low price established a small but growing market, and several merchants of Key West began to buy the better grades and take them in trade from the fishermen.

It is said that at first they paid only 10 cents a pound for sheepswool sponges; but, as the product became better known, the price improved, capital was invested in the industry, and a large group of men began to rely on gathering sponges for their livelihood.

* Deceased.

At first the fishery was confined to the waters adjacent to the Florida Keys, but from about 1868 to 1879 extensive beds of superior sheepswool sponges were found in the Gulf of Mexico, north of Cedar Key, and a little later south of that point, extending as far as Anclote Key. Key West maintained its supremacy in the sponge market until about 1899, when Tarpon Springs, more advantageously located in respect to the valuable Gulf of Mexico grounds, supplanted it. The introduction of diving in 1905 and the establishment of Tarpon Springs as the headquarters for the Greek divers, confirmed the position of that place as the principal market. At present over 85 per cent of the total product of Florida sponges is marketed through the sponge exchange, a nonprofit organization established in 1908.

Decline in Production

The production of sponges in the United States steadily increased from 1920 to about 1936–1937, when it reached its maximum of over 600,000 pounds, valued at more than 1.2 million dollars. In 1937 the industry employed 72 diving outfits, 256 sponge hooks, and gave livelihood to 949 fishermen. The decline in the quantity of sponges on fishing grounds brought down the production figure to only 158,000 pounds in 1947. The scarcity of sponges greatly increased their price, and in 1946–1947 the value of the industry was 2.9 and 1.7 million dollars, respectively, greatly exceeding the 1936–1937 figures in spite of the decreased production.

The decline of the sponge fishery has not been limited to Florida waters, but affected the entire Western Atlantic production, which dropped from 1,750,000 in 1938 to only 300,000 pounds in 1947.

The principal cause of the decline has been the blight or wasting disease which appeared in the fall of 1937 on the sponge grounds of the Bahamas and rapidly spread over the entire West Indies. The disease extended as far south as British Honduras, where it destroyed a large stock of cultivated sponges grown at Turneffe Lagoon, while in the north it depleted the natural grounds, from Key West to Carabelle, Florida.

Investigation, conducted jointly by the American and British biologists, determined that the cause of the disease was a fungus infection which was spread by a system of water currents. The blight was particularly severe among the cultivated and densely planted sponges at Andros Island (Bahamas) and in British Honduras.

Since the recovery of sponge populations on the affected grounds has been very slow, the former productivity of the grounds may not be restored in less than 20 or 30 years. The situation is aggravated by the complete lack of scientific management of sponge resources. Sponge grounds off the Florida Coast have never been surveyed, and consequently no accurate information exists of their extent and present population density. Likewise, the biology of American commercial sponges has been so little studied that data of their reproduction, rate of growth, normal mortality, as well as the knowledge of the ecological conditions affecting sponges, are lacking. In the absence of these essential data no practical conservation measure could be suggested.

At present the enforcement of a 5-inch minimum size law is the principal con-

servation measure. The law is, however, not too strictly enforced, and incidents of its violation (e.g., selling of undersized sponges) are frequent.

Statistics

The statistics of the world's sponge production cannot be stated with accuracy. Those of the United States, the Bahama Islands, and Cuba can be given with considerable exactness, but the fishery of the Mediterranean, the most important of all, is conducted by so many nationalities, overlapping in their fields of activities and in their markets, that it is difficult if not impossible to detect omissions and duplications in the published data. Sometimes it is evident that the same sponges are reported in part both for the country under whose jurisdiction the beds are lodged and by that whose nationals conducted the fishery.

Table 161 represents the best estimate that can be made at present on the basis of the available data. The total figure is slightly underestimated, for the production figures are not available for the Philippines, Japan, and the Far Eastern Area (the Marshall and Caroline Islands).

TABLE 161. WORLD PRODUCTION OF SPONGES.
In pounds

Country	1938 000 omitted	1947 000 omitted
United States	610	160
Cuba	440	100
Bahamas	670	40
Other Caribbean	30	
Total western Atlantic	1,750	300
Greece	90	330
Turkey	80	80
Egypt	100	30
Syria-Lebanon	10[1]	
Libya	70[1]	
Italy	110[1]	
Tunisia	230	110
Other Mediterranean	10	10
Total Mediterranean	700	560
Total world	2,450	860

[1] Included in "Other Mediterranean."

Source: U. S. Fish and Wildlife Service, Department of the Interior, and Foreign Service, Department of State.

Living Sponge

The limits imposed on the length of this chapter will not permit more than a cursory account of the structure and life history of these interesting animals.

The living sponge, fresh from the sea, has no resemblance to the sponge of the markets. It is a solid, rather slimy-feeling fleshy body, varying in color from light greyish yellow through a considerable range of browns to black; in shape it varies with the species, age, and habitat. In general appearance and consistency

it is not unlike beef liver, and is traversed by numerous chambers and canals.

It is covered by a skin raised at intervals into blunt little cones and perforated by small pores leading into subsurface cavities. These canals run into the interior, their walls punctured by innumerable minute holes, each of which leads into a microscopic pear-shaped chamber, which in turn opens by a larger pore into a canal. These canals, uniting with others, become gradually larger until they again reach the surface in one of the large openings scientifically designated as oscula, but known to the spongers as "eyes" or "vents."

The pear-shaped chambers are lined with innumerable microscopic lashes or cilia, which, by their rhythmic beating, set up a current of water entering by the small pores and escaping from the vents, thus carrying food and oxygen to all parts of the sponge.

There are tissues of various, but not markedly differentiated, kinds in the fleshy mass of the sponge; but the important economic feature is the skeleton, which, freed from the fleshy matter, constitutes the sponge of commerce. This is composed of a substance related in general chemical and physical properties to silk, horn, and chitin, the foundation of the shells of insects and crabs. This substance, called spongin, is arranged in a fibrous network varying in structural details in the different sponges; but for each the thickness of the fibers, the sizes of the microscopic meshes, and the relations of the several parts, one to another, lie within definite limits of variation. Embedded in the core of the large main fibers there is always some foreign matter, such as sand grains; but an excess of such materials in or on the fibers makes the sponge harsh and otherwise inferior for commercial purposes.

Little is known of the life history of the commercial sponges. In some species, if not all, the sexes are distinct, females preponderating. The young produced from the eggs are free-swimming organisms, and are still very small when they settle and become permanently attached. This must be a critical stage in their life, for they are so minute that a very thin stratum of silt would be sufficient to engulf and smother them. As much of the sea bottom is covered with soft or shifting deposits, the mortality at this period must be very high.

Within the limits of variation of the species sponges, in shape, rate of growth, texture, etc., are creatures of their environment, and when transplanted are often quickly modified in general characters. They require for their existence water of nearly full oceanic salinity. If kept moist they tolerate exposure to the air for considerable periods during cool weather, and in Florida they grow from about low-water mark to a known depth of 150 feet, and probably more. In the Mediterranean they occur to depths of 500 to 600 feet. That the food is taken into the sponge wholly or in large part through the canal system is practically certain, but of what it consists is not known.

Description of Commercial Sponges

The sponges of commerce, as they appear on the market, are only the skeletons or supporting framework from which the soft fleshy matter of the living animal has been removed. This skeleton consists of fibers of a material which has been called spongin, and it is upon the physical properties of this material and the way in which the fibers are disposed that the economic value of sponges depends.

The fibers of commercial sponges vary in diameter, but are always fine and

comparatively, but not wholly, free from embedded sand and other siliceous matter, which imparts to some closely related species a harshness and makes them unfit for domestic and industrial use. The network formed by the fibers is composed of small, close meshes. The qualities affecting the commercial value of sponges are color, size and shape, softness, fineness, durability, resiliency and absorptiveness.

Color is the consideration of least intrinsic importance, though for esthetic reasons it exerts considerable influence on the market value. As the color is often incidentally correlated with other qualities, due to local conditions, it is of value in distinguishing the grades and geographical varieties.

Size and Shape. The most desirable size (and to some extent the shape) depends on the use to which it is to be put: For surgical and some toilet purposes small ones are desired; for the bath a medium size; while for cleaning vehicles a large sponge holding a considerable quantity of water is necessary. Sponges up to 8 inches in diameter are commonly used entire and called "forms"; while large ones or those that are irregular or torn are usually cut into pieces called "cuts."

The valuable commercial sponges are regular, more or less massive, and free from long processes or "fingers." They are spheroidal, cake-shaped, conical, or cupped; a great many are of intermediate shape. For general purposes the more desirable forms are the spheroidal and cake-shaped; but for such work as applying glaze to pottery a flat surface is desired, and this is generally obtained by cutting up a massive form or by using pieces of a smooth-surfaced lamellar sponge, like the Mediterranean elephant's ear.

The more desirable grades of sponges are those which are softest. Sponges with comparatively slender fibers, with the microscopic meshes rather open, with a small amount of foreign matter embedded in the spongin, and with an open canal system are the softest. Those with the fibers laden with sand are invariably harsh.

Fineness depends upon the macroscopic rather than on the microscopic arrangement of the skeleton, though the slenderness of the fibers is a factor. The Matecumbe sheepswool is one of the softest sponges, but its open structure makes it appear coarse when compared with Mediterranean kinds. Fineness in the same species, like other qualities, varies more or less with the environment under which the individual is produced. Toughness and durability vary greatly with the species, and in the same species, with the conditions under which the sponge grows.

Resiliency. Resiliency is the property of sponges which causes them to recoil after being pressed. It depends on the size and the arrangement of the fibers and, to a certain degree, on the method of curing and thoroughness of cleaning. Sponges which rapidly regain their original shape after compression are much more useful than those which are sluggish in their reaction.

Absorptiveness. The ability to absorb and retain a large volume of water is the fundamental quality which determines the usefulness of a sponge. Sponges with fine meshes, slender fibers, and a close texture absorb more water than those with large canals and big cavities. Absorptiveness depends on a combination of other qualities, namely, softness, fineness, and resiliency. The fibers themselves absorb only a small amount of moisture, the water being held primarily by the capillary action of the sponge skeleton.

Chemistry

Sponges of the markets consist principally of spongin, an albuminoid related to conchiolin found in the shells of mollusks, and fibroin and sericin, the principal constituents of silk. Its composition is reported to be:

C 46.50	H 6.30	N 16.20	S 0.50	(Croockewitt)
C 48.75	H 6.35	N 16.40		(Posselt)

In 1898 Hundeshagen demonstrated the occurrence of iodine and bromine in organic combination in different sponges, and designated the albuminoid containing iodine, *iodospongin*. Harnack (1898) later isolated from the ordinary sponge, by cleavage with mineral acids, an iodospongin which contained about 9 per cent iodine and 4.5 per cent sulfur. On the acid hydrolysis of spongin Abderhalden and Strauss (1906) obtained 18.1 per cent glutamic acid and 13.9 per cent glycocoll, as well as 7.5 per cent leucine, 6.3 per cent proline, and 4.1 per cent aspartic acid. By the use of dilute acids Strauss (1905) has obtained *sponginoses* of various kinds from spongin. The heterosponginose contained the greater part of the iodine and sulfur, while the deuterosponginose contained the carbohydrate groups. Iodospongin is considered a derivative of the heterosponginose.

More recent studies identified the iodine compound obtained from spongin as di-iodo-tyrosine, a complex which also contains bromine. The physiological role the iodine plays in sponges is not known.

No complete analyses of entire sponges, with the fleshy matter in situ, appear to have been published. The Bureau of Soils, U. S. Department of Agriculture, investigated the organisms as sources of fertilizer, and found that an air-dry horny sponge contained moisture 13.90 per cent, silica (SiO_2) 1.41 per cent, nitrogen 7.41 per cent, phosphoric acid (P_2O_5) 1.17 per cent, and potash (K_2O) 1.64 per cent.

Sponge Culture

In 1785 F. Cavolini, an Italian, made the observation that pieces of living sponges would attach to foreign bodies and grow, and in 1862 Oscar Schmidt repeated the observation and suggested that it offered the basis for developing a method of sponge culture. The suggestion was taken up in 1867 by certain merchants of Trieste, who established an experiment station. Since then experiments have been conducted by Munroe, Harris, Dubois, Allemand-Martin, and others in the Mediterranean, and by the government of the Bahama Islands. The essential procedure of all of these experiments has been to cut the living sponge into pieces, which were attached in various ways to different kinds of supports.

The method finally adopted by H. F. Moore was to fasten pieces of 8-inch sponge to cement discs about an inch thick and 10 inches in diameter, attachment being made by means of an aluminum wire thrust through the sponge and passing through a hole in the disc. Information concerning this method and others and a more complete history of the subject may be found in papers cited in the bibliography.

These methods were tried on a commercial scale at Anclote Key and Sugar Loaf Key, Florida. At the former location the sponges were killed by an influx of fresh water, and at the latter the project was abandoned for reasons other than technological and biological.

The practicability of sponge farming was demonstrated by the success of the projects sponsored by the British Government in the Bahamas and British Honduras. From 1935 to 1939 more than 140,000 velvet and wool sponges were raised by the government on the well-protected planting grounds of Andros Island, Bahamas. In British Honduras sponge farming was centered at Turneffe Lagoon, about 30 miles east of Belize, where approximately 800,000 sponges were under cultivation in May, 1939. In both localities the sponges were almost completely wiped out by a blight, and since this time sponge farming has not been resumed.

Cultivation, as it was practiced in both places, consisted in growing sponges from rectangular pieces about 2 inches × 4 inches × ½ inch, cut with a very sharp knife from a healthy sponge and attached with a string to a piece of rock or cement disc. It is important that sponges be returned to water as soon as possible. Under these conditions regeneration begins immediately and the sliced piece firmly adheres to its base. In the Bahamas sponges grown from cuttings reach marketable size within 4 years. Cultivation of sponges was also practiced by the Japanese in the Marshall and Caroline Islands. Sponge cuttings were attached to concrete discs, strung on aluminum wire suspended from rafts, or anchored to the bottom and kept afloat by means of a sealed bottle. Cuttings were placed at 4-inch intervals. A series of 4 to 5 wire lengths were joined together and suspended from one bottle, which was floated 6 inches below the surface at low tide. The method of suspending the cuttings from the floating bottle gave the most satisfactory results.

It is very interesting that a specimen of cultivated sponge collected by R. O. Smith in Ailinglapalap Atoll in the Marshalls was identified by M. W. de Laubenfels as *Spongia officinalis,* subspecies *mollissima* known as Fine Levant or Turkey Solid of the Mediterranean Sea. In answering the question of the origin of this sponge and the method of transportation the Japanese authorities emphasized that all the sponges used for cultivation in Ailinglapalap Atoll were of local origin and no Mediterranean species was introduced into these waters.

Commercial Varieties

Both the scientific and commercial classifications of economic sponges are confused and unsatisfactory, and the two are often contradictory. These animals are so extremely plastic and susceptible to influences of local environment, changing appearance, and details of form and general structure under different physical conditions of the bottom and water that satisfactory descriptions are almost impossible.

The classification employed in commerce is much more complex than is indicated here, as all the sponges named are further differentiated according to geographical origin, quality, and even the methods by which they are taken. Among American sponges, in addition to the various geographical and local designations, we have "forms," "cuts," and "seconds," while in the Mediterranean certain of the commercial species are subdivided into "fines," "commons," "seconds" or "rejects" (écarts), "plongées," "harponées," etc. The significance of the discrimination between the same kind of sponges taken by different means is that they may come from different depths of water, may receive different care in curing, or are less mutilated by one type of apparatus than by another.

Federal specifications for natural sponges recognize 11 various types which are designated by different names as, for instance, "Rock Island Sheepswool Middle Range Forms No. 1," "Florida Key Sheepswool No. 2," etc., and two classes—unbleached and bleached. There are from 1 to 6 sizes in various types, defined by average minimum and maximum perimeter measurements and by the number of sponges per pound. Details of these complex specifications are given in the Federal Standard Stock Catalog Section IV, Part 5 (1941).

Table 162. Commercial Sponges.

Common name	Scientific name	Sources
Turkey cup or solid	*Euspongia officinalis mollissima*	Mediterranean
Turkey toilet	*Euspongia officinalis adriatica*	do
Zimocca	*Euspongia zimocca*	do
Elephant ear	*Euspongia officinalis lamella*	do
Honeycomb	*Hippiospongia equina elastica*	do
Sheepswool	*Hippiospongia lachne*	Bahamas, Cuba, Florida, Honduras, Jamaica
Velvet	*Hippiospongia grossypina*	do
Yellow	*Spongia barbara* (probably other species also)	Bahamas, Cuba, Florida, Honduras, Jamaica, Mediterranean
Grass	*Spongia graminea*	Bahamas, Cuba, Florida, Honduras
Glove	*Hippiospongia canaliculata* var. *flabellum.*	Bahamas, Cuba, Florida
Reef	*Spongia obliqua* (probably other species also)	Bahamas, Cuba, Florida, Honduras
Hardhead	*Spongia dura* and *S. agaricina corlosia* (probably other species also)	Bahamas, Cuba, Honduras
Wire	Not known	Cuba, Florida

Sheepswool or Wool Sponges. These are the best of the sponges of the western Atlantic, and in some of their qualities and for some purposes are not equaled by any other kind. They are massive in form, usually cake-shaped or like inverted pineapples, and regular in contour, with the exception of certain specimens from Cuba which have a flat incrusting base from which rise long teatlike tubes often reaching a length of 6 to 8 inches.

Sheepswool sponges are particularly responsive to environment, exhibiting wide local variation both in appearance and quality and undergoing marked change in character when transplanted to a new locality. The oscula are large, few in number, confined to the upper surface, and surrounded by a rampart of flat tufts usually slightly elevated above the surrounding tissue. The whole surface of the skeleton is tufted with fascicles of fibers, which are usually more slender and pointed in sponges from shallow water. Sheepswool sponges grow to a large size, 18 inches or more in diameter, and are soft and absorbent; the better grades are unequaled in wearing qualities. The smaller and medium sizes are marketed as "forms," while many of the larger ones and the irregular or torn ones are divided and sold as "cuts."

Unbleached sheepswool sponges are used for washing railroad cars, automobiles, and other vehicles, and are popular among tile and bricklayers, painters, decorators, potters, tanners, etc. Key wool, on account of its softness, is said to be particularly desirable for lithographers. When bleached, they are used principally for bath and household purposes. The best sheepswool sponges are the "Rock Island" sponges from the west coast of Florida; the successively less valuable grades are those from the Florida Keys, Bahama Islands, and Cuba. Those from Mexico, Honduras, and other localities in the Caribbean are inferior.

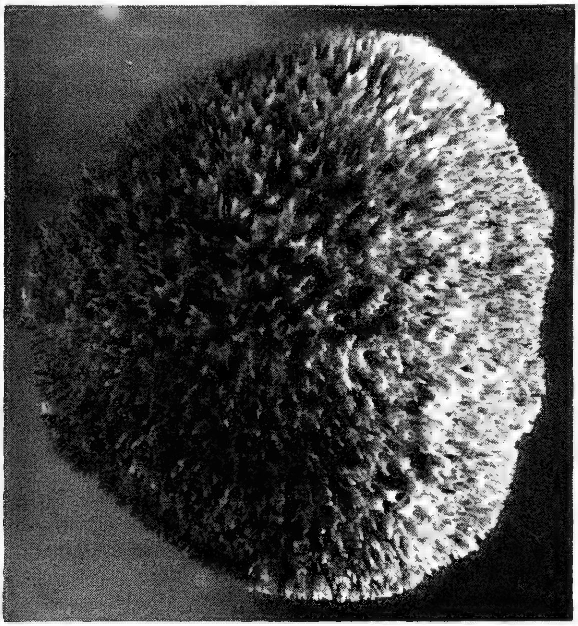


Fig. 35–1. The sheepswool sponge from the Florida Keys.

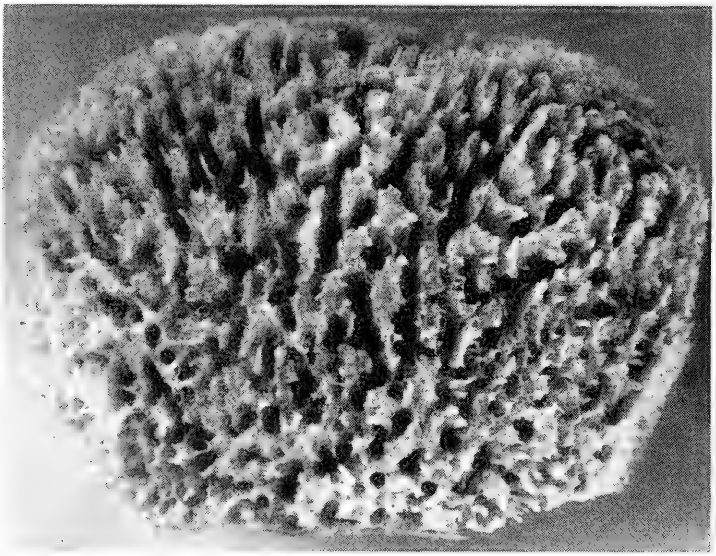
(Courtesy U. S. Fish and Wildlife Service)

Yellow Sponges. Yellow sponges are the next most valuable sponges of the western Atlantic because of their abundance and wide distribution, although their unit price is a little lower than that of the velvet sponge. They are the most elastic and resilient of American sponges, with the exception of Anclote grass, but are harder than sheepswool, harsher to the touch, less absorbent, less retentive of water, and less durable. They are regular in shape, attractive in appearance, and reach a maximum diameter of about 18 inches. The color is yellow or yellowish brown, those from some localities being tinged with rusty red. The surface is devoid of the long fibrous filaments characteristic of the sheepswool, and is covered with a nap of short bristles of uniform length.

In their natural state yellow sponges are used for many of the same purposes as the sheepswool, but are distinctly inferior where durability, softness, and a copious water content are required, as in washing vehicles. Owing to their hardness and comparatively harsh surface they are said to be particularly useful for scouring. The best of the yellow sponges, the softest and most durable, come from the vicinity of Matecumbe Key. Other yellow sponges on the market come from the west coast of Florida ("Anclote yellow"), the Bahamas, and Cuba. They

are also found in the Honduras, Haiti, and other places in the Caribbean. Similar sponges have been reported from Australia, New Zealand, and some of the Pacific Islands.

Velvet Sponges. Velvet sponges are generally cake-shaped or spheroidal. The surface is devoid of the pointed or sharp-edged tufts characteristic of the wool sponges or the harsh bristles of the yellow; on the contrary it consists of rounded or flattened soft cushions, the outer faces of which lie in the same plane, imparting a smooth appearance. These cushions may form meandering ridges or flat



(Courtesy U. S. Fish and Wildlife Service)

FIG. 35–2. The velvet sponge. This specimen was taken from Cuban waters.

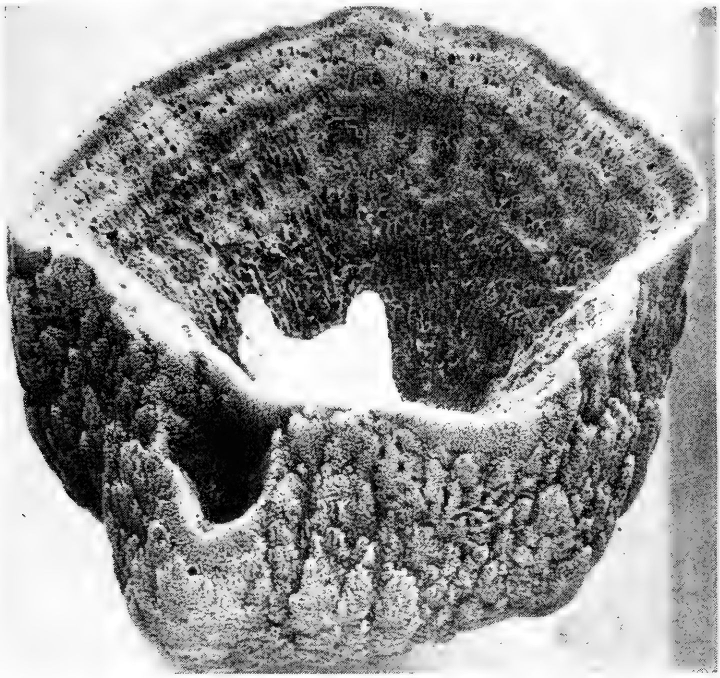
brush-shaped tufts. One to 3 large ragged holes in the upper surface serve as vents or "eyes," and divide internally by irregular torn-looking septa into numerous circular openings. Jamaica specimens are high rather than broad, and are often subcolumnar; the vents consist of single or double rows of openings on the summits of branching crests running across the top of the sponge, an arrangement which makes, in effect, a gash almost completely across the upper surface.

Good velvet sponges are very soft to the touch, but in wearing qualities, compressibility, and absorptiveness are inferior to sheepswool, to which they are next in value, though not differing much from the yellow.

They are used for household purposes, for boats, for washing vehicles, and for general purposes in factories, and by painters, brick and tile layers, etc. The best come from the Bahamas, particularly from the vicinity of Abaco Island. The Cuba velvet is better than that from Florida, where the species is found in but small numbers and only in the vicinity of the reefs at the southern end of the state. British Honduras has produced a few velvet sponges about equal to those of Cuba. Those from Mexico and Haiti are inferior.

Grass Sponges. The grass sponges of commerce comprise a group of several zoölogical species, and each varies to such an extent with locality that space will not permit an attempt at description.

The best are the Anclote grass sponges from the west coast of Florida which grow to large size, and for that reason and on account of their hollow wastebasket



(Courtesy U. S. Fish and Wildlife Service)

FIG. 35–3. A grass sponge containing a large piece of coral in depression.

shape are generally sold as "cuts." They are dirty brown in color, harsh to the touch, highly elastic and resilient, but will not hold as much water as other grass sponges. They are especially useful where there is much oil, as greasy matter is readily washed out of them.

The grass sponges from the Florida Keys, Bahama Islands, and Cuba vary in form and general appearance, and are entirely different from those just described. They are softer, more compact in shape, and much weaker in texture. Especially when bleached, some of them make soft, attractive bath sponges, but they have little durability. Though unsatisfactory substitutes for the better grades of sponges, they are useful where softness and absorptiveness rather than wearing qualities are desired. There are some good sponges of this type in the Philippine Islands.

Glove Sponges. The shape of the glove sponge is almost invariably that of a short, stout column, with the sides fluted with irregular vertical ridges between which are 1 or 2 rows of round holes about ⅛ inch, more or less, in diameter. These ridges are frequently swollen at their free margins, and they always bear

long ragged pencils of fibers. They begin just above the base of the sponge and extend over the top, near the center of which is a large ragged-edge compound vent.

Glove sponges are found on the south and west coasts of Florida, and in the Bahamas. They are soft and elastic, but on account of their open texture and weakness have little value. Those from the west coast of Florida are worthless.

Wire Sponges. These sponges have a fine massive regular shape, and an attractive color and texture, but owing to their harshness, lack of strength, and inability to hold water they are of little usefulness. Formerly, they were rarely brought in by the spongers, but the Greek divers now market a limited quantity. They are bleached and sold, often fraudulently, as substitutes for the Mediterranean bath or honeycomb sponge. They are taken on the west coast of Florida.

Reef Sponges. Reef sponges belong to several zoölogical species and vary in shape, although comparatively uniform in qualities and surface appearance. The surface mesh is regular, covered with short bristle-like bundles of fibers, and bears innumerable round orifices about 1/16 inch in diameter. Although they superficially resemble some of the finer grades of Mediterranean sponges, they are far inferior in strength and durability. The pores are larger and the projecting bundles of fibers stouter and stiffer. A few of these sponges are taken among the Florida Keys; but those found in the markets come from the Bahamas, the north coast of Cuba, and occasionally from Honduras.

They are used by jewelers, silversmiths, and other manufacturers requiring a small, soft sponge. They are used as desk sponges and, when bleached, for toilet purposes.

Hardhead Sponges. These constitute another miscellaneous group. They are less compressible than reef sponges, and more harsh, elastic, and resilient. They are,

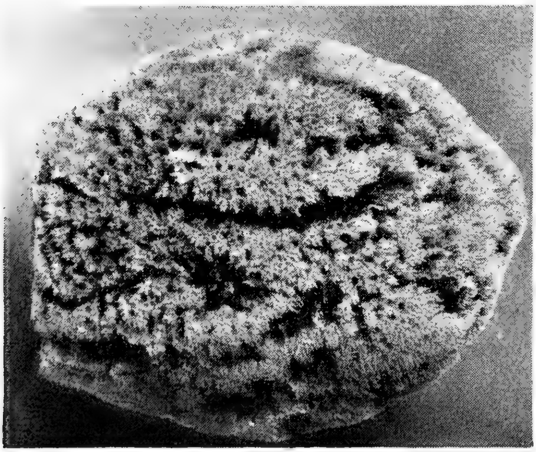


FIG. 35–4. The hardhead sponge.

(Courtesy U. S. Fish and Wildlife Service)

in general, regular in form and, like the reef sponges, usually small. The softer ones are used for the same purposes as reef sponges, the harder ones for scouring and similar operations where a certain degree of attrition is desirable. They come principally from the Bahamas, the north coast of Cuba, the Honduras, and occasionally from Haiti.

Turkey Cup and Turkey Solid Sponges. These and the kind next described are also known as "silk" sponges. They are the finest and softest, one of the most elastic sponges known to the markets, and notwithstanding their delicate texture are very durable. Some of them are massive; but many are more or less cup-shaped, though perfect cups are rare and bring high prices. It is said that large, unusually choice specimens have sold for $50.00 each.

The oscula or vents are comparatively large and numerous, and are grouped on the upper surface of the solids or in the cavity of the cups. There are numerous small round or polygonal pores on the general surface, the partitions between them being very thin and beset with long slender and very soft fibrous pencils. Foreign bodies in the fibers are sparse and this, with the rather open elongate meshes of the microscopic structure, give the sponge its exquisite softness and firmness.

These sponges come from the eastern Mediterranean, the very finest from the Syrian coast. It is stated that the best of them grow in the semidarkness of caves, crevices, and under overhanging ledges. They sometimes attain a diameter of 8 inches, but most of those reaching the market measure only a few inches across. They are used for the more exquisite purposes of the toilet.

Turkey Toilet Sponges. Most of these sponges belong to a zoölogical subspecies differing from the preceding, but some inferior Turkey solids are often included in this commercial class. They are flatter than the cup sponges, and have a broader basal attachment to the rocks. The vents are usually distributed over the upper surface, except toward the edge, and are sometimes in groups. Generally each is surrounded by a rampart of bristles. The surfaces, other than those bearing these openings, are perforated by numerous fine pores, the intervening ridges have sharper edges than in the cup sponges, and the pencils of fibers which they bear are shorter, stouter, and stiffer. The sponge is less compressible and not so soft to the touch. Toilet sponges are generally found on all the sponge grounds of the Mediterranean, eastward from the Adriatic and the Tunisian littoral. They are used for toilet purposes, in leather dressing, and in applying glaze to fine pottery, as well as for other operations in the arts which require a fine soft sponge.

Zimocca Sponge. These are massive sponges, usually flatly conical. They are attached by a relatively small base, sometimes flat on top, sometimes concave, occasionally cup-shaped. The vents lie on the upper surface, usually generally distributed, but occasionally in irregular, radial rows, and in many cases surrounded by a hedge of bristly fibers. The outer surface is formed by a network of narrow ridges, inclosing numerous small pores and bearing short bundles of fibers which become longer and softer upward.

These sponges are taken commercially along the coasts and about the islands of the Mediterranean, from the Adriatic eastward and southward and westward to Tunisia and the banks of Lampedusa. They have been taken in small quantities west of this region to the coast of Catalonia.

They are used by potters, leather workers, and, when bleached, for toilet purposes.

Honeycomb or Bath Sponges. These are massive cake-shaped sponges attached by a broad base. The vents are scattered over the upper part of the sponge, and only occasionally are surrounded by a hedge of fibers. The surface is composed of superficially expanded plates of fibrous tissue, often extending as a network over

subsurface chambers, clothed with small blunt tufts, particularly around the edges of the numerous circular, polygonal, or meandering openings. The general superficial aspect of the sponge is less shaggy than the sheepswool, and not so smooth as the velvet sponge.

Honeycomb sponges are generally distributed throughout the Mediterranean, along the north, east, and south shores from the Gulf of Lyons to Algeria, including many of the islands and the banks of Lampedusa. The Mandrukas are the best—compact, soft, and fine; but those from Tunis, Crete, and Asia Minor are only a little inferior, and are often sold as Mandrukas. Those from Tripoli are rough and coarse, and most of those from the Archipelago but little better.

The best of these sponges are softer than any American sponge, except the Matecumbe sheepswool; but they are less durable and resilient than the Rock Island wool, and more quickly lose their elasticity in use.

Honeycomb sponges are very popular for bath purposes, and they are also used by jewelers, silversmiths, leather workers, and as desk sponges by bank tellers, etc.

Elephant-ear Sponges. These are cup-shaped, or cap-shaped, and have thin walls of uniform thickness, or more or less rolled ear-shaped or fan-shaped plates about 1 inch thick. They usually reach the consumer cut into flat pieces, the shape of which gives the name of "washrag sponge." The vents are in groups of 4 to 6, surrounded by tufts of fibers longer than those in the rest of the sponge. They are confined to the inside of the cups, or to the concave faces of the plates.

These groups are generally in radial rows, and the face of the sponge, on which they open, often has the appearance of being radially grooved. The opposite surface is covered with soft fibrous tufts, which tend toward a radial arrangement near the rim. Elephant-ears are taken commercially in the Adriatic, the Aegean, on the coasts of Egypt, Tunis, and Algeria, and about Lampedusa and the Balearic Islands. They are fine, soft, and durable, and are used for toilet purposes, and by potters, fine leather workers, cane makers, and hatters.

A sponge of very similar appearance, but much denser and harsher, is found in the Philippines.

Methods of Fishery

Sponges grow attached to the bottom, or, less frequently, to other objects under water; the few unattached individuals, usually of spheroidal shape and known to the spongers as "rollers," are those which have been violently torn from their attachments.

Wading. The first sponges gathered in Florida, and probably in other regions, were plucked by men wading in the shallows. To this day the natives of the southern part of Tunisia follow a similar method, wading in the water to their necks, detaching the sponges with their toes, and kicking them within reach of their hands and occasionally diving into the deeper holes.

Nude Diving. This is another ancient method which logically followed the primitive method first described. It is practiced principally in the Mediterranean and a little in the sponge regions of the western Atlantic. The islands of Calymnos and Syme have been noted from ancient times for the skill of their divers, some of whom are said to be capable of descending to a depth of 240 to 250 feet. Ordinarily about 2 minutes is spent under water, and about 30 minutes between plunges; but usually expert divers can remain under water for 4 minutes, and

in a few cases 5 minutes' immersion has been recorded. The Syrians, Tripolitans, and Tunisians also practice nude diving.

To carry them quickly to the bottom the divers carry flat stones attached to a line, the other end of which is held in the boat. When the diver reaches the bottom, he drops the stone, but retains hold of the line, or has it attached to his arm by a short lanyard or becket. The sponges are deposited in a net bag attached to the diver's waist; when he is ready to ascend, he jerks on the life line and is rapidly hauled to the surface.

Although nude diving requires more skill and training than "machine" diving, and is not so productive, it is not attended by the serious physical effects of that practice. This method is most useful on bottom too rough for dredging, where the sponges are hidden in crevices or under ledges which hide them from harpooners, or where sharp rocks are liable to injure the diving suit or hose.

Hooking and Harpooning. These methods are essentially the same although their instruments differ. Neither can be used when the sea is rough or the water turbid, and those employing them often lose much time by enforced idleness.

The harpoon is used in the Mediterranean sponge fisheries only. It resembles the ancient trident, but may have from 2 to 5 barbed points or prongs, the type varying locally and with the nationality of the user. The steel heads are attached to poles about 20 feet long and 1½ inches in diameter. At the free end of the pole a short piece of wood is lashed; this is so notched as to leave a space between itself and the pole into which the head of a second harpoon may be thrust and held in place by a rope ring or becket. In this manner 3 or 4 harpoons are sometimes lashed together in order to reach sponges in deep water.

The sponges are sighted by means of a "water telescope," a cylinder of sheet iron about 8 to 10 inches in diameter, and 15 inches long, with a sheet of glass closing one end. When the closed end is thrust a few inches beneath the surface of the water, the bottom becomes clearly visible in moderate depths.

The apparatus is used from small boats about 20 feet long, each usually provided with a lateen sail and 2 pairs of oars, the latter being the means of propulsion when sponging. A man crouches in the bow watching the bottom, and when a sponge is sighted signals to the oarsman to maneuver the boat into proper position. He then inserts the harpoon into the sponge, which is detached by a series of gentle jerks, accompanied, if necessary, by a rotation of the pole.

Hooking is the American variant of this method, the differences in practice being that the instrument of capture is a hook, with 3 recurved unbarbed points, that the water telescope is an ordinary wooden bucket with a circle of glass replacing the wooden bottom, and that the boat or dinghy carries only 2 men instead of 4 and is propelled by a single oar skulled over the stern. The length of the poles varies with the depth of water, the longest being 50 feet, used in depths of 40 to 45 feet. Very few men have the strength, eyesight, and skill to work in such deep water.

Hooking was the only method of sponging practiced in Florida until the introduction of the diving dress on the west coast, and it is, or was until recently, the exclusive practice in Cuba and the Bahamas.

Machine Diving. The diving suit has been employed in the fisheries of the Mediterranean since about 1866, but it was not until 1905 that it was successfully introduced in Florida. Its advantages are that it permits the exploitation of

deeper waters than is possible by the use of the methods already described, and therefore vastly extends the available sponging grounds; that the sponges on those grounds are better and more abundant; and that operations may be conducted under weather and water conditions which would prohibit the use of other methods. The disadvantages are that more capital and equipment are required, and that there is greater peril to the life and health of the divers.

The diving suit is of the usual type, completely covering the body with the exception of the hands. It is made of 2 layers of waterproof cotton cloth with rubber between, a tinned copper helmet, breastplate, and weighted shoes. The helmet has 4 heavy glass windows, and a hose connection and relief valve at the back. The automatic relief valve for the discharge of vitiated air does not appear to be in favor with the sponge divers, who prefer the spring valve opened as necessary by pressing against it with the back of the head. The pump is of the usual type used by divers. The hose which conveys air under pressure to the helmet is of the highest quality; it is protected by a canvas jacket, and the weight of the screw couplings between its sections is compensated in the water by the buoyancy of cork floats.

Sponge divers, both in the Mediterranean and in Florida, are almost exclusively Greek, and the Greek type of diving boat is used in both places. The boats are "double-ended," high bow and stern, and with considerable shear, features which make them seaworthy and dry in any weather. They are usually rigged with a spritsail, but all those in American waters now use gasoline engines, and are equipped with a cage of metal bars around the propeller to prevent the fouling and cutting of the hose and life line. Formerly, even in the engined boats, oars were used in keeping the boat up to the diver as he moved over the bottom, but experience has proven that the engine may be used for this purpose.

Space will permit only a limited description of this method of sponging. When the diver is fully dressed and the hose and life line are attached, the pump is started and he lets himself over the side of the boat. As soon as he reaches bottom, he gets to his feet and moves about in search of sponges. Owing to the resistance of the water and buoyancy of his air-filled suit he is unable to walk in the ordinary way, but progresses in a series of leaps upward and forward. As sponges are found, they are placed in a bag, which, when full, is hauled to the surface on the life line and an empty one sent down. Communication between the diver and the boat is maintained by a code of tugs on the life line.

The length of time that a diver can remain under water depends on the depth and the physical powers of the man. On the Florida coast, in depths of 60 feet or less, the shift is usually 2 hours down and 2 hours rest. In deeper water the period of submergence is shorter and the rest longer.

Divers in deep water are subject to the "bends," or caisson disease, due to the release of air in bubbles in the blood vessels as a result of the rapid change from the pressure in the helmet to that of the atmosphere when they are brought to the surface. Owing to the comparatively shallow water in which diving is conducted in Florida fatal or serious cases are few there; but the proportion of deaths and disablement among the Mediterranean divers is high, and for their protection the Greek laws prohibit marine diving in greater depths than 124 feet. This law appears to be generally ignored.

Neither naked nor machine divers eat until the day's work is completed.

A new type of mechanical diving aid, known as the Fernez apparatus, has come into use in the Mediterranean since about 1912. The diver is naked, except for a rubber mask fitted with goggles, air valves, tubes, etc., and the air is carried from a small pump on the boat, through a hose, to a small reservoir attached to the back by a belt, and thence to the mask and its respiratory appliances. It compares favorably with the diving suit at equal depths, usually from 65 to 130 feet.

Dredging or Trawling. This method of sponging is confined to the Mediterranean, where it is practiced principally by Greeks and Sicilians. The dredge, gangava of the Greeks, or gagova or cava of the Italians, is a special type which has been developed for this fishery. The frame consists of a heavy round steel bar about 35 feet long and 2½ inches in diameter, bent at right angles about 12 or 15 inches from each end. These turned-up ends are formed into sockets, into each of which a stout wooden stake is driven and secured by metal pins or bolts. The bar and stakes form the lower side and ends of the frame, the upper part of which is a wooden beam about 6 inches in diameter, with rabbets near the ends to receive the tongues or flattened ends of the lateral stakes. There are several transverse steel struts connecting the steel and wooden bars, the whole forming an open rectangle about 32 feet long and 20 inches wide. To this frame is attached a quadrangular net of rope, with a mesh of from 2½ to 3½ inches bar. A bridle is formed by a rope running from the middle of the wooden beam and 3 or 4 chains attached to the steel bar near the ends and at 1 or 2 intermediate points, all united in an eye or ring to which the towing warp is attached.

This apparatus is towed at a speed of about 1 to 1½ knots per hour by sailing vessels of about 20 to 40 tons burden, fitted with 3 winches and the necessary davits and towing bitts, which cannot be described in detail within the limits of this chapter. When in use the relative lengths of the several members of the bridle, the buoyancy of the wooden beam, and the weight of the steel bar, keep the frame erect with the bar scraping the bottom and tearing loose the sponges and other organisms on the bottom, which are retained in the bag. From time to time the gangava is hauled aboard and the contents of the bag discharged on deck and sorted, the sponges being retained and the considerable quantity of debris dumped overboard. The crews consist of about 6 men each.

Preparation of Sponges for Market

The preparation of sponges for market is a comparatively simple process. When taken, the living sponge is covered with a "skin" or membrane, and a large part of the interior is filled with a soft, pulpy, fleshy substance. Both of these must be removed, leaving the skeleton clean. The sponge is first killed and then macerated to liquefy the putrescible matter which is then washed and squeezed out.

The hookers in Florida formerly killed their sponges by prolonged exposure to the air, "roots" down, on the decks of their boats, after which they placed them in "crawls" about 10 feet square, made by driving mangrove stakes close together in shoal water. After an interval of about a week they were removed, beaten with a short heavy stick and squeezed repeatedly under water. When properly done this removed the fleshy matter thoroughly; but the sponges often accumulated much sand from rolling on the sandy bottom of the crawls.

When diving became common on the Florida coast, the Greeks introduced the methods used in the Mediterranean: The sponges are placed on deck and killed

by thorough treading under the bare feet of the crew, after which they are strung and hung over the side of the boat to macerate, and are then thoroughly washed on deck in tubs of sea water. Unless these processes are thoroughly performed, some fleshy matter or skin is left adhering to the fibrous skeleton, which, after drying, is very difficult to remove. Such improperly cleaned sponges are said to be "gurried."

After being cleaned the sponges are strung on rope yarns 6 feet long, the ends of which are tied together to form wreaths, called "bunches." The sponges are partially dried and carried to the primary markets, where they are sold in lots to the dealers at auction. In the hands of dealers the sponges are trimmed with sheep shears to remove the irregularities, torn parts, and gross foreign bodies, such as shells, pieces of coral, etc. They are then sorted into sizes, designated by the number of pieces required to make a pound; these are usually "ones," "twos," "twos to threes," "threes to fours," "fours to sixes," "sixes to eights," "eights to tens," "tens to twelves," "twelves to sixteens," and "sixteens to twenties."

In Florida, Cuba, and the Bahama Islands the different kinds and sizes of sponges are packed separately in quadrangular bales, covered with burlap and strongly roped while under compression in a screw press. The bales vary in size according to the immediate demands of the trade. In the Mediterranean sponges are packed under foot pressure in boxes or in cylindrical bales weighing about 40 to 75 pounds.

Sponges sold by weight are frequently artificially "loaded" by the wilful introduction of foreign matter, sand or marble dust being usually employed for the purpose in the Mediterranean. No "loading" is permitted by the Tarpon Springs Sponge Exchange.

The accepted fair-trade practice in the United States for selling pressed sponges in bales is to allow 3 per cent of gross weight for tare (rope and burlap). The custom dates back to the beginning of the industry when prices were low and bales weighed 150 pounds or more. At present, when bales are often smaller, it acts as a reasonable price differential in favor of the larger purchases.

Most of the sponges from the western Atlantic are sold in their natural color; but some are bleached, as is a large part of the Mediterranean product. The method usually employed is as follows: Soak the sponges for about 10 minutes in 5 per cent hydrochloric or sulfuric acid; then thoroughly wash in water and place in 5 per cent potassium permanganate solution until they have assumed a very dark brown, almost black, color; thoroughly wash again in fresh water and place, until almost decolorized, in a 10 per cent solution of oxalic acid; after another very thorough washing place in a 10 per cent solution of sodium carbonate (washing soda) until they assume a bright yellow color. A very thorough washing completes the process. The fiber of all chemically bleached sponges is more or less injured by the treatment, and though softer they are inferior to the natural sponges in durability and resiliency and soon become soggy in use.

REFERENCES

Abderhalden, E., and Strauss, E., "The Monoamino Acids of the Keratin of *Testudo graeca*," *Zeitschr. f. physiol. Chem.*, 48, 535–536 (1906).

Galtsoff, P. S., "Wasting Disease Causing Mortality of Sponges in the West Indies and Gulf of Mexico," *Proc. 8th Am. Scientific Congress* 3, 411–421 (1940).

Galtsoff, P. S., "Sponges," *Encyclopedia Britannica,* 15th Ed., **21,** 253–260 (1947).

Harnack, E., "Concerning the Iodospongin the Proteinaceous Iodin-Containing Substance of the Sponge," *Zeitschr. f. physiol. Chem.,* **24,** 412–424 (1898).

Moore, H. F., "The Commercial Sponges and the Sponge Fisheries," U. S. Bureau of Fisheries *Bull.,* **28,** Pt. 1, 403–511 (1908).

Moore, H. F., "A Practical Method of Sponge Culture," U. S. Bureau of Fisheries *Bull.,* **28,** Part 1, 545–585 (1908).

Smith, F. G., "Sponge Mortality at British Honduras," *Nature,* **144,** 785 (1939).

Smith, R. O., "Fishery Resources of Micronesia," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **239,** 1–46 (1947).

Strauss, E., "Researches on the Albuminoids," *Biochem. Centralbl.,* **3,** 513 (1905).

Stuart, A. H., "World Trade in Sponges," U. S. Dept. Commerce, Office International Trade, *Industrial Series,* **82** (1948).

CHAPTER 36

Some Problems of the Fisheries

Introduction

While the fishing industry is one of the oldest in this country, only within the last 3 decades has use been made of scientific research to increase profits. This change has been gradually brought about by increased costs of production and foreign competition. It has been extremely difficult for a comparatively small industry, such as this, to undertake research, except on a limited scale. A few large firms have established well-equipped and staffed research laboratories; these, however, merely serve to solve the problems which interest their owners, and usually the results of their researches are not released to the industry as a whole.

Research is financed, to a greater or lesser degree, by the governments of many foreign nations. The extent of this financing depends, to a large extent, upon the importance of the fishing industry in the economy of the country. The geographical location and agricultural land area of the country, as well as other factors, influence the consideration given to the fisheries. It is only natural that those nations having long coast lines and small agricultural land areas should turn to fishing. This in turn leads to governmental support of research directed toward increasing the food supply.

Our own Federal government has found it necessary to finance fishing research only to a limited extent. In 1948, $5.73 of Federal funds were spent on agricultural research per ton of food produced, and only 90 cents per ton for fisheries. This is largely due to sectional competition and disorganization; the agricultural interests, on the other hand, are highly organized, and are in a strong position to enforce their demands for assistance. Sectional rivalry and competition among the fishing interests remains the most difficult problem.

Formerly the Bureau of Fisheries, of late the Fish and Wildlife Service, had done much in the way of research for the fisheries. This Service is inadequately financed, and with the small appropriations made available by Congress has done more to assist the fisheries technically, in proportion to the funds expended, than any other similar government agency. So many requests for assistance are received by this Service that only those of the widest application can be undertaken. The Fish and Wildlife Service operates technological laboratories at Boston, Mass., College Park, Md., Seattle, Wash., and Ketchikan, Alaska.

The laboratory at College Park is located adjacent to the University of Maryland. A cooperative arrangement is in effect by which research fellowships, financed by both the Fish and Wildlife Service and the University, are granted to qualified graduate students. Research deals with technical problems of the fisheries, and is carried on under the supervision of both the University and the scientific personnel of the technological laboratory. Graduate degrees have been granted in

the fields of the chemistry of fish oils, bacteriology and sanitation of shellfish, determination of amino acids in fish protein, nutrition, and home economics. These fellowships have also extended into the field of biological research.

Attempts have been made, with only partial success, to interest other educational institutions located adjacent to the laboratories in a similar arrangement. Some of these institutions prefer to conduct the research on fishery subjects with their own personnel. In some of these fishery subjects are included with the courses in general food technology. Fishery biological courses are given in most universities.

It is unfortunate that so few of those who have been the recipients of these fellowships have made fishery technology their life work. Generally there were no suitable openings in the industry for them when they had completed their training. This has led highly qualified technically trained graduates to seek employment in other fields. This situation can be corrected only when a larger segment of the industry becomes "research conscious."

Salting

The problems confronting the fisheries at present are numerous and vary widely. It is impossible to designate any one as the most important, because no one can predict when any investigation is to be completed and the final result obtained. For example, it was found in a study of salting fish in warm climates a number of years ago that the physical properties of the salted fish could be controlled largely by varying the amounts of calcium and magnesium compounds in common salt. Furthermore, it was learned that pure salt produced a soft flexible fish with an appearance and taste resembling that of fresh fish. However, much trouble is experienced with a red discoloration and the oxidation of the oil in salted fish.

While the consumption of salt fish in this country is now at a minimum, it is highly important in the tropical and semitropical countries. It is also of importance in most European countries, where the population is more accustomed to using salt fish.

Utilization of New Species

Only a few years ago the rosefish (*Sebastes marinus*), a brilliantly colored fish found in the North Atlantic, was of no commercial importance. It was taken by the fishermen in their trawling operations for cod and haddock and usually thrown overboard. As the catch of cod and haddock began to decline for various reasons, the exploitation of other species became necessary. A quantity of rosefish was landed in Boston; fillets were cut from them, skinned and frozen in 1-pound packages, and shipped as "ocean perch" to dealers in the Midwest. Consumer reaction was favorable immediately. Since then the demand has exceeded production, and this former trash fish is now found in the markets of the large cities, even on the Pacific Coast.

During World War II several species of fish, which had not heretofore been considered suitable for food, were exploited with a considerable degree of success. The rockfish (*Sebastodes*) of the Pacific Coast was one. Some species of shark prepared as steaks and fillets were consumed to some extent; but it was difficult to maintain a high quality product because of the nature of the protein composing

the flesh. Research could develop methods for the treatment of this protein so that it could be stabilized, and thus increase the demand for shark meat.

There is an abundance of carp (*Cyprinus carpio*) available in all the fresh-water lakes and streams of the Midwest. These fish are considered a nuisance and are seined out to make room for the more desirable species. Little use is made of those thus destroyed. One small cannery attempted to pack them as canned "fish flakes" in the last years of World War II. Insufficient study and research was given to the preparation of this product, and a ready market has been difficult to find. A sizable market could probably be developed if the technique of preparation and process were perfected. As an alternative, while these fish contain only small amounts of oil, the protein is highly valuable, and they could be reduced to fish meal which would find a ready market.

These are only a few illustrations of problems in the field of marketing new species of fish. There are many other species of fish little utilized at present because of unfounded prejudice against them. One of the reasons for this is the lack of widespread advertising which would familiarize the public with the qualities of these fish. It is only since World War II that home economists of the Fish and Wildlife Service have conducted cookery demonstrations. Popular in public school lunchrooms and before groups of housewives, these demonstrations should be given on a far larger scale.

Utilization of Fish Livers

The problem of supply and demand for fish-liver oils of high vitamin A potency has, to a large extent, been solved. However, many processes for the recovery of vitamin A are inefficient and in need of improvement. Many of the fish livers used in the production of this vitamin contain only small quantities of oil. Vitamin A is combined with the protein of the liver so that the recovery requires the destruction of the protein molecule. After the vitamin has been removed, the remaining material, which contains partially digested protein, is discarded. Research into possible methods for the recovery and utilization of these waste products would probably lead to the establishment of an entirely new industry, which would be beneficial to both fishermen and processor.

Most of the processes used for the recovery of vitamin A from fish livers do not remove the last traces. Research is under way to increase the efficiency of these methods.

There is concern among the processors of fish livers over the possibility of the loss of their markets through competition from the new less expensive synthetic vitamin A. It would be well worth-while for them to have studies made of the relative therapeutic values of the natural and synthetic vitamin A; as yet, this has been done only to a limited extent. It is possible that deficiencies in the synthetic product may more than offset its lower cost to the consumer.

There is a considerable demand for bile acids for the production of various pharmaceuticals. The fish livers do not contain large quantities of this material, but gall bladders have to be removed from the livers before they are packed for the vitamin A processor. If these were preserved in a separate container instead of being thrown overboard, they could add to the income of the fishermen when sold to the producers of these acids. There is a market for these if they are handled carefully and are well-preserved prior to sale.

Fish-Freezing Problems

The production of frozen packaged fish has made great advances, and a good quality product is now available in most cities of the United States. There remain, however, many problems in connection with this industry which need to be solved. Some of the most difficult pertain to production. In general, fishing takes place in temperate areas, that is, in areas where the temperature of the water seldom rises above 50° F (10° C). In order to accommodate themselves to their surroundings fish maintain body temperatures that are seldom more than 1 or 2 degrees above the surrounding water temperature. When they are caught and landed on the deck of the vessel in an air temperature of 60 to 80° F (15.6 to 26.7° C), autolytic deterioration is greatly increased. It is doubled or tripled, depending upon the air temperature and the length of time required before the fish can be stored in crushed ice in the hold of the vessel.

In many instances a week to 10 days lapse between the time of capture and the landing of the catch at points of production where the fish can be prepared for packaging and freezing. Even though fish remain packed in ice throughout this period, autolysis continues at a reduced rate. As a result, fresh landed fish are often of inferior quality.

Freezing fish on board the tuna clippers has been common practice for a number of years. It is estimated that these vessels equipped to freeze fish at sea cost between $300,000 and $500,000. All tuna frozen in this manner go to the canneries. However, several vessel operators are investigating the possibility of improving the quality of other fish by freezing at sea. Several vessels, equipped for the preparation of frozen packaged fish, are now in operation. However, many of the operational problems involved in this instance remain to be solved in a satisfactory manner.

The characteristics of the flesh of fish introduce some additional problems in handling. The fat content varies considerably with different species, and within the species, depending upon the season of the year. It is one of the most easily oxidized of all fatty substances, and even at temperatures considerably below 0° F (− 17.8° C) it becomes rancid and imparts unpleasant flavors and odors to fishery products. As far as present knowledge indicates, there is no way to prevent limited oxidation in all species, even those with relatively low fat content. Only moderately successful attempts have been made to eliminate this difficulty. Even storage in an almost complete vacuum is not entirely satisfactory. The theory has been advanced that there is a chemical rearrangement of the components making up the fat, particularly when it is in contact with protein.

Enzymatic action of the fish flesh also causes deterioration in cold storage. It has been proven that the gradual breakdown of the tissue of the flesh continues even when the fish are frozen and stored at low temperatures. Shellfish are more susceptible to this type of breakdown than any other fish. In some of the laboratory tests carried out by the Fish and Wildlife Service it has been shown that deterioration takes place in fish even in sealed glass jars, which entirely exclude the air.

Although ways to stop enzymatic action in frozen fish have been given some attention, the problem is far from being solved. Consideration is being given to the treatment of fish with some of the numerous anti-oxidants to prevent ran-

cidity of the fat. Both of these problems are highly important in cases where it is necessary to hold frozen fish in cold storage over a period of months. The length of time fish are held and the temperature of storage are the most important factors in determining the quality of the stored product.

The importance of the proper type of wrapping materials has been pointed out many times. These can cause serious losses in storage, in both the quality of the product and a direct loss of weight to the producer. This applies to all frozen packaged products. If 1 ton of product is placed in a cold storage warehouse and loses even as little as 1 per cent of its weight in the form of moisture, 20 pounds is lost.

The quality of various types of wrapping materials has been investigated for many years. Some of these materials are highly efficient for regular-shaped packages. Most packages of fish cannot be completely filled because of the irregular shape of the fish put into them. In these packages there are spaces filled with air, and even though the wrapper is successful in excluding outside air, there is a sufficient amount entrapped to do considerable damage. A packing material is needed which is flexible enough to fit the contour of the irregularly shaped fillets of fish and leave no air space. It should not become brittle when cold and should not deteriorate when placed in cold storage over a period of many months. A wrapping material which is completely satisfactory would do much to eliminate losses caused by freezer burn and oxidation in frozen fish.

One highly efficient wrapping material has been developed from synthetic material, known as the "Cryovac" bag when formed. This bag can be drawn over a package of fish and shrunk by dipping in hot water until it fits skintight. Freezing does not affect the flexibility of the material. However, large fish, such as salmon and halibut, are difficult to handle since the fins often puncture the material and render it worthless for preventing evaporation.

Many species of large fish, such as halibut, salmon, and swordfish, are frozen and stored whole. To protect these species during long storage periods, it is necessary to replace the glaze at intervals. These intervals vary in length, depending upon the temperature of the storage room and the humidity maintained. If some type of covering material could be produced which would fit the fish like its own skin and yet be impervious to the transfer of moisture vapor and oxygen of the air, it would eliminate the necessity of reglazing, and thereby save the warehouse operator hundreds of dollars. It would also result in a higher quality stored fish since it would eliminate freezer burn and oxidation to a large extent.

Shellfish Freezing Problems

Problems of the storage of shellfish are of considerable importance to the industry. Many shellfish do not store well when frozen. Clams are seldom frozen for long storage as they become rubbery. Shrimp and crabs become tough and lose much of their flavor when stored frozen for too long a period of time. Oysters often turn black and become strong upon long periods of storage. These problems should be thoroughly investigated.

A problem of major importance to the frozen-fish industry and to all frozen-package food industries is that of the education of the retail dealer in the proper ways of handling these products. Much has been accomplished along this line, but there are still many hundreds of retail merchants who display their frozen

package foods in a case with only crushed ice as a refrigerant, or without any refrigerant. Often packages of fish and other foods which were in excellent condition while frozen are held until completely defrosted before being finally sold to the consumer. This is a problem which the industry cannot afford to overlook.

Utilization of Fish Waste

Use of the entire fish is the rule in fish-packing establishments. More and more plant operators are taking steps to utilize the entire fish rather than only that portion which can be used as a fillet or placed in a can. There still remains one considerable area where little use is made of the waste products from canning fish. In the Territory of Alaska it is estimated that 50,000 tons of cannery waste are discarded annually.

This wasteful practice is not intentional, but there are several problems involved which as yet have not been solved. Many of these canning plants are located on isolated Alaskan bays and inlets far from any city or town with a nearby farming community which could utilize the processed waste products. Personnel to operate the cannery is often transported from the United States. The season usually lasts from 3 to 6 weeks, after which time the personnel returns to their homes. During the canning season tremendous quantities of salmon are handled in one day, and a plant to reduce the waste would be overloaded far beyond its capacity. Salmon waste is so highly perishable that it would be extremely difficult to store. The investment in money and costs of upkeep for a plant of sufficient capacity to reduce the waste as it is delivered from the cannery would be prohibitive. The nearest market for the waste products is in the agricultural areas of the United States. The costs and uncertain facilities of transportation of the fish meal and oil to the markets are also extremely unfavorable. Few reduction plants are in operation for these reasons.

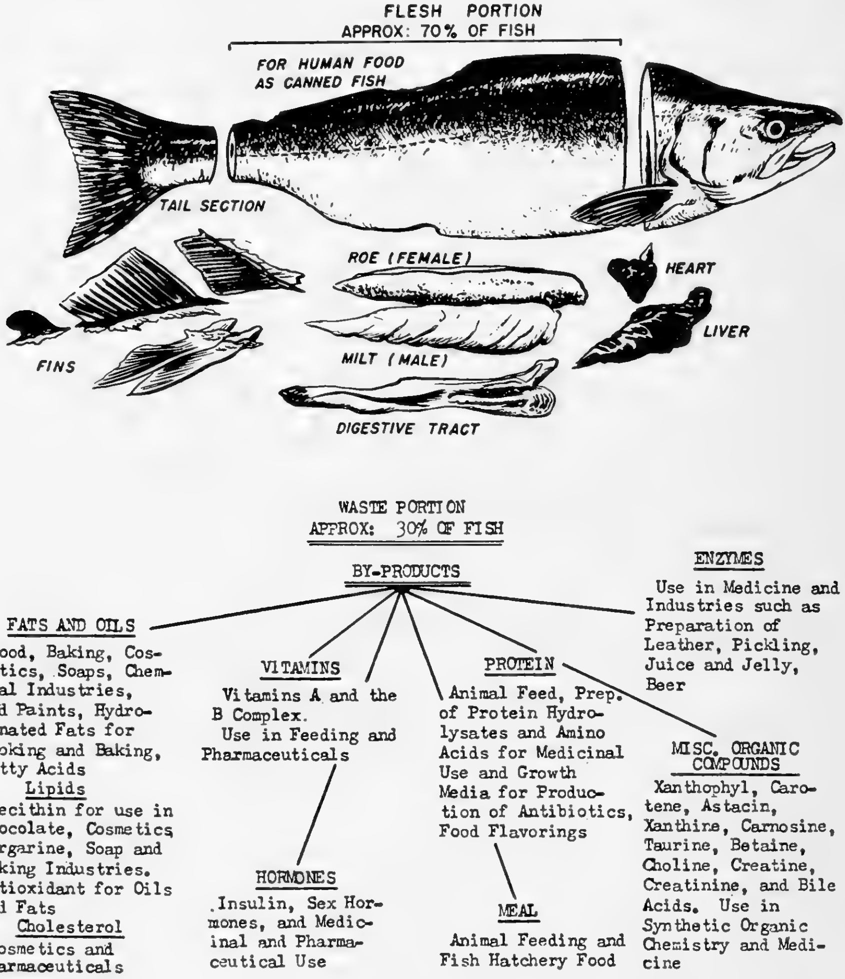
A solution to the problem of complete utilization of the salmon resource will be obtained only when a method for waste preservation is devised. The waste may be used in the production of materials of greater value than meal and oil. Some research along these lines has been undertaken by the technologists of the U. S. Fish and Wildlife Service and the Canadian Fishery Research Laboratories. Of main concern thus far has been the production of materials of greater value than fish meal and oil. There is an indication that the waste material is rich in cholesterol and a commercial grade of lecithin, as well as an oil with an iodine value of 200. These products are all of greater value than the fish meal.

While a successful preservative in the form of "Aquacide" is available for such material, it appears that the chemicals of the preservative might affect the value of the material for some pharmaceutical products which are contained in it. The usual method for preserving many of the glands and other organs for the preparation of pharmaceuticals is by freezing. It is possible that an economical method for freezing these organs from the waste may be devised and put in commercial operation.

As this study progresses, it is expected that insulin will be produced commercially since the demand now exceeds the supply. It is not inconceivable that this waste material may be a source for many of the enzymes and hormones now in demand. It has been demonstrated that certain parts of fish viscera contain an extractable material of value in the treatment of pernicious anemia. Crystalline

pepsin can be prepared from the stomach of salmon and bile acids have been prepared from the gall bladders.

While all of the above mentioned products and many more have been produced from salmon waste in the laboratory, nothing has been done as yet to convert lab-



(Courtesy U. S. Department of Commerce)

FIG. 36–1. Potential utilization of salmon cannery waste.

oratory methods into full-scale commercial production. Until commercial production for these products is accomplished, the salmon waste problem in Alaska will not be solved.

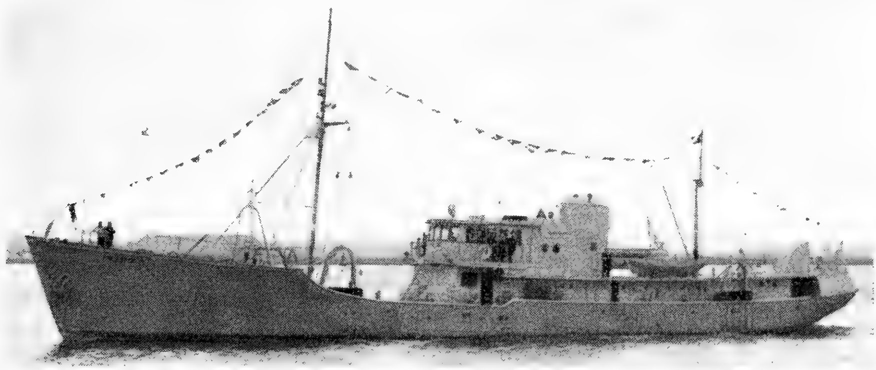
A chief difficulty in the utilization of these products is the separation of the various valuable organs so that they can be used. No doubt, as the importance of the complete utilization of this resource is impressed upon the industry, mechanical means will be devised to effect an economical method of separation. In this way

it will be possible for economical products to be offered to the distributors of the miscellaneous pharmaceuticals available from fish waste.

Fishing Studies

The production of fish has been gradually increasing from year to year, but to continue this it has been necessary for the fishing fleet to travel further and further from its home ports. The costs of production have thus arisen in proportion to the distancės traveled.

The Fish and Wildlife Service has several vessels in operation for investigations intended to assist the commercial fisheries. Some of these vessels are for the purpose of exploring the fish populations and migrations. Many species of fish used as food seem to become scarcer periodically, then after a few years they return in numbers greater than ever before. It is the purpose of these vessels to determine, if possible, the reasons for these periodical depletions. In addition to the factors affecting the depletion the studies will include climatic changes, ocean currents, availability of food, the salinity of the water in various areas, the fishing intensity of the commercial fleet, and the ocean temperatures. Efforts will be made to connect the various factors with the rise and fall of fish populations from year to year. The vessels which are equipped to make these investigations are fitted with laboratory space, and the scientists assigned to them are furnished with living quarters. All of the data collected will be analyzed, and the relation between the fish population fluctuations and conditions of the ocean will be studied. If and when these relations are partially or completely understood, it will be of value to the fishing industry in planning its operations.



(Courtesy U. S. Fish and Wildlife Service)

FIG. 36–2. The *Albatross III* is the third in a long line of fishery research vessels which have sought to improve the fishing conditions along the Atlantic Coast.

Other vessels are fitted out to study the effects of the utilization of various types of gear. These vessels will also explore the possibilities of fishing in areas where the fleet does not ordinarily fish. Some studies have been made in the Gulf of Mexico, in the Bering Sea and in the waters around Hawaii. These studies have indicated that many areas of the ocean contain vast quantities of fish which have not been exploited. Many new species of fish which are totally unknown in the

markets of this country are excellent food and are available in sufficient quantities to be worthy of commercial exploitation.

These vessels are fitted with freezing and refrigeration equipment, and studies are being made of possible improvements of handling fish at sea so that a higher quality, more tasty product can be introduced in the markets. To be most effective this type of investigation should be expanded to a far greater extent by the Federal Government.

Several universities and colleges are making similar studies in the waters adjacent to the shores of the states in which they are located. Among these are the Universities of Washington, California, North Carolina, Southern California, Miami, Harvard, Columbia, and Yale.

The European nations, which are dependent to a considerable extent on fish to supply food for their national economies, are probably far more research conscious than the United States. The British, Norwegians, Danes, and Dutch operate varying numbers of research vessels to investigate fish populations and prospect for new fishing grounds.

The Japanese, who are far more dependent on their fisheries to supply protein foods than any other country, have financed exploratory fishing to a far greater degree than any other nation. The Japanese fishermen have explored the resources of every area of the Pacific Ocean, and have exploited many of them.

An international compact, drawn up recently by 11 countries which fish in the North Atlantic, establishes a commission for the conservation of the fisheries in this area. This commission is similar to that on the Pacific for the control of fishing in the Gulf of Alaska and the Bering Sea. Since the international agreement governing the fishing for halibut in this area was signed, this species has made a remarkable recovery. It is possible that similar control of the same fishery in the North Atlantic would result in a similar recovery of this species in this area. It is expected that conservation measures applied to the cod and haddock fishery will result in a recovery of these species to their former abundance and economic importance.

Other Uses for Sponges

All along the coast of Florida are found great quantities of sponges, of little or no commercial value for that purpose. However, these sponges contain a high percentage of very pure silica in crystalline form. As yet only minor use has been made of this resource, which would yield other chemicals of value as by-products. Some attempts have been made to prepare a poultry food from this source, but due to the inefficient method of manufacture this has not been entirely satisfactory.

Utilization of Algae

In only a few instances are any attempts made to utilize the great quantities of seaweeds which are common to all the waters of the ocean along the coast of the United States. While large sums of money have been spent by private industry in the development of new products from certain species of seaweed, the Federal Government has been quite conservative in sponsoring research in connection with such developments. The Scottish Seaweed Research Association has financed research, which equals if not surpasses that of the United States, in the utilization of seaweeds. Much interest has been expressed in the possibility of

again producing iodine and bromine from some of the species of seaweeds available on the Pacific Coast of the United States. It is also possible that some species of seaweeds can be utilized in the manufacture of insulation for various purposes.

New types of fishing gear and new methods of operating the present gear for the capture of fish have been promoted. In general, the gear now used in capturing different species of fish is the result of years of evolution. Purse seines and trawlers are used for the capture of fish on both the East and West coasts of the United States. These are generally alike, but the methods of operating them and the types of boats used are entirely different. As each seems to be equally efficient when used individually, it is possible that a combination of the two might be far more efficient and far easier to handle. Furthermore, the new one might be as efficient on one coast as on the other (i.e., as effective in taking tuna and pilchard on the West Coast as in taking mackerel and herring on the East Coast). The new type of gear could be much easier to operate, and thus save work for the fishermen.

The foregoing problems are only a few of the great number which might be pointed out. The technical talent of the United States might well consider the field of fishery research as one of great opportunity.

Problems of International Significance

by Mogens Jul

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While the largest areas of water on the earth are in the southern hemisphere, approximately 95 per cent of all marine products—excluding whales and whale products—are caught in the northern hemisphere. This, however, does not mean that the southern hemisphere has extremely limited fisheries resources, but that most of the present fisheries activities are found in northern waters. It is, therefore, natural to assume that production could be greatly increased in other areas if fisheries were intensified. This assumption has been confirmed in recent years when several countries, for instance, Chile, Peru, and the Union of South Africa, have deliberately increased their production from a rather small beginning.

Several biological investigations have already shown the existence of still unused fisheries resources in many areas. On the basis of these alone it can be said that there is room for considerable development, not only in the southern hemisphere, but also in other areas where heretofore little fisheries exploitation has taken place.

Knowledge of Resources Needed

On the whole, however, our knowledge of the extent of the resources of the oceans is still very limited. Therefore, one of the most important contributions which research could make toward an increase of the commercial utilization of the marine resources would be extensive biological investigations of the less-known areas and fisheries. However, such research must be aimed at determining not only the existing resources, but also, as far as possible, how they can best be obtained and the extent to which they can stand continuing exploitation. Any research of this nature will, therefore, have to be combined with fishing or sim-

ilar experiments involving the actual operation of various types of gear, boats, and other equipment.

Such an effort is particularly necessary because it is often very difficult to determine which fishing methods could be used in the exploitation of fishery resources, regarding which no previous fishing experience exists. Here, existing and well-known fishing operations are relied upon too often. However, most major fishing operations and methods have been worked out through many years of experience and experimentation, and have thereby been specially adapted to whatever local conditions they are carried out under. For instance, both purse seining and trawling operations are used extensively on both the east and west coasts of the United States, but both the gear and methods used differ very considerably. Sardine purse seiners from the Pacific Ocean seem to be of little value if used in the menhaden purse-seining operations off the east coast. Similarly, a New England trawler would not be effective if used in the trawling operations for flatfish carried out in the Pacific Ocean. Thus, different conditions require different types of equipment, even if conditions in many respects seem to be very similar.

New Fishing Methods Needed

Even greater adaptations will be necessary if fishing operations are to be transplanted to entirely new regions. Methods and equipment will have to be adapted, not only to the climate, habits of fishes, and conditions of the sea, bottom, etc., but also to the traditions and abilities of the people who carry out the fisheries. The methods which can be used will depend largely on experience in navigation and seamanship, as well as eating and working habits, etc.

Much experimentation in gear and methods is therefore necessary when new marine resources are to be developed. There is, however, also a great need for such research in countries which already carry out intensive fisheries. It is noteworthy that until recently only little effort has been made to carry out technological research in this field. Tank experiments are needed to determine the best shape of the fishing boat, and tests to determine the exact reaction of nets under various conditions.

Little is known about what actually happens when fish are caught in a net. Underwater films, which are now being planned by the fisheries biologists in several countries, and direct observations might reveal many unknown factors regarding the reaction of the fishes to the gear. Such research might result in an alteration in the design of the nets.

It must also be realized that the fishing methods which are in use at present have, to a very large extent, been developed through gradual adaptations of already known methods; new methods have been tried very little. Today large-scale experiments are being carried out with floating trawls of radically new design, electric fishing devices, etc.; but it is to be expected that much more experimentation will be needed in this field in the future.

It must be kept in mind, however, that any attempt to establish new fishing industries or to increase the existing production depends on the existence of proper outlets for the catch. This is particularly important in areas where fisheries have heretofore been limited. Several development schemes in such regions have been unsuccessful because the effort was concentrated mainly on the increase in production. The local populations, however, were in these cases not used to eat-

ing fish, and an increase in fish production alone naturally did not affect the demand for fresh material. In such cases efforts have to be made to introduce fish into the diet of the population and also to secure an adequate distribution system. The other choice is, of course, to attempt to establish processing industries which can manufacture staple products for which there is a ready market elsewhere. It is evident from this that any research which will contribute to the improved or extended distribution or utilization of commercial marine products is just as important as any research regarding fisheries resources or fishing methods.

Handling and Distribution

Some of the primary problems are those related to the handling and distribution of fresh fish. Fresh fish are still preferred to frozen fish in a great many markets, partly due to taste preferences and partly also to the somewhat lower price and easier distribution. Most fish-processing industries are also dependent on receiving their raw material in as fresh a condition as possible, which makes improvement in fresh-fish handling equally important for them. The high perishability of fish is the main obstacle, and continued research has to be carried out to improve sanitation, refrigeration, etc. Research might also reveal that it would be possible to add small tasteless and harmless bactericidal substances which, even in very small concentrations, are known to prolong the storage life of fresh fish 50 to 100 per cent. There have been attempts in recent years to bring about partial sterilization by various means of irradiation, supersonic treatment, etc. No such method has been commercially successful so far, but research might still find a means of improving such processes or overcoming the difficulties which they have encountered.

In the long run the trend will undoubtedly go toward the development of more and more staple food products. Salting of fish has for many years been the main method of preservation. It seems, however, that as technical development gives the consumers access to more varied food products their interest in salted fish products will decline; but it is not unlikely that products could be treated with a combination of salt and spices, etc., which would be much more palatable than the cruder prepared products which have heretofore made up the bulk of the salt-fish trade. For instance, the so-called delicatessen products are highly palatable and very popular in certain countries; they are prepared from the same type of herring which is otherwise used mainly for salted herring, a product which is sold at much lower prices to less discriminating groups.

Of other staple or semistaple fishery products fermented fish sauces have a wide market in the Far East. Little technological research has ever been carried out with a view of rationalizing the manufacture of these products to improve the fermentation cultures, etc. In addition to these products there are in the Far East a number of other staple fishery products prepared according to methods which vary greatly compared to those used in other parts of the world. Research and improvements in this field would be particularly important because these products are used extensively in some parts of the Orient. It is likely that they would be much more acceptable in other parts of that region than, for instance, many of the customary European or North American fishery products. Therefore, research regarding their manufacture, nutritive value, etc., would be highly useful.

By-products

The field of fishery by-products, particularly fish meal and oils, has already been extensively investigated. Undoubtedly much more can be done in this field. For instance, many fish oils, which at the moment are used for technical purposes, contain appreciable amounts of vitamins which are destroyed in the further chemical treatment of the oils. It is not unlikely that research would find methods by which these vitamins could economically be separated from the oils.

When considering the field of fish meal and oil it is necessary to realize that there are at the moment very considerable quantities of valuable fish proteins which are used for fish meal (i.e., mainly for feedstuffs for domestic animals). This is, of course, an excellent way of utilizing these proteins which come mainly from waste products, offal, or from less palatable fish of little commercial value. Through the utilization as feedstuffs they are eventually turned into high quality foods; but the yield is low. As a rule it is difficult to recover more than 20 per cent of the original food value of the proteins. From a purely nutritional standpoint it would therefore be better to use such proteins directly for food. They must be first made acceptable and usable in some form. This might be done by purifying the proteins, as has been done for many years in Germany, where such proteins were used as egg-white substitutes. These proteins might also be used in a somewhat less purified form in bread. Experiments in Norway have shown that up to 6 per cent of such fish flour can be added to bread without any objectionable effects, thereby highly improving the nutritional value of bread.

Utilization of Plankton

The amount of plankton in the oceans is of a far greater magnitude than that of all larger animals or plants. This plankton is highly nutritional, and it has been found that the high content of certain vitamins in cod-liver oil is not synthesized in the cod itself but can be traced back to the vitamin content in certain plankton diatoms. Thus, if one could find ways of utilizing the plankton resources directly, the food production from the sea could be multiplied a great many times. German scientists have already proved that edible fats can be manufactured from plankton, and experiments have shown that plankton can be used directly for food. Any commercial application still seems to be in the future, not only as a result of difficulties of manufacturing suitable food products from plankton, but also due to the difficulties of designing methods for the collection of this material. However, such possibilities which may contain promises for entirely new and important commercial products should be recognized.

REFERENCES

Anon., "Research Goes to Sea," Cambridge, Mass., Arthur D. Little, Inc., *Industrial Bull.*, **256** (1949).

Anon., "Utilization of Alaskan Salmon Cannery Waste," Pts. I and II, U. S. Department of Commerce, *Office of Technical Services* (1947–1948).

Anon., "Protamin from Salmon Milt of Medicinal Value," *Pacific Fisherman*, **34**, No. 7, 29 (1936).

Anon., "Large Development in Fishery By-products Seen," *Fishing News*, **33**, No. 1675, 19 (1945).

Beall, D., "Effluent Losses at Pilchard Reduction Plants," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations*, **20**, 14 (1934).

Bergman, W., Schedl, H. P., and Low, E. M., "XVIII, Micromasterol and Other Sterols of Sponges," *J. Org. Chem.*, **10**, 780 (1945).

Bertrand, I., and Quevy, D., "Influence of Protamines on Coagulation of Plasma," *Compt. rend. soc. biol.*, **148**, 780 (1944).

Brocklesby, H. N., "The Chemistry and Technology of Marine Animal Oils with Particular Reference to those of Canada," Fisheries Research Board Canada, *Bull.*, **59** (1941).

Carter, N. M., "Pearl Essence from Scales of British Columbia Herring," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **55**, 18 (1943).

Cook, N. E., "A Note on the Cost of Salmon Bile," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **70**, 18 (1947).

Deas, C. P., and Tarr, H. L. A., "The Value of Fish and Fish Products as Protein Foods," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **69**, 66 (1946).

Fruton, J. S., and Bergmann, M., "The Specificity of Salmon Pepsin," *J. Biol. Chem.*, **136**, 559 (1940).

Hurley, Stanley P., "Sanitation Problems in the Fishing Industry," *Food Technology,* **3**, 416, 418 (1949).

Hickman, K. C. D., "State of Vitamins in Certain Fish Oils," *Ind. Eng. Chem.*, **29**, 1107–1111 (1937).

Jacobsen, F., "An Investigation of Polymerized Marine Mammalian Oils. Part II, Detection, Composition, and Structure," *Tids. Kjemi. Bergvesen Met.*, **6**, 52 (1944).

Jacobsen, F., and Nergaard, R., "Investigations on Polymerized Marine Animal Oils for the Norwegian Canning Industry. Physical and Chemical Means of Identification," *Tids. Kjemi. Bergvesen Met.*, **3**, 68 (1943).

Jacobsen, F., and Solvig, K., "Investigation of Oil Used in the Norwegian Canning Industry in 1943," *Tids. Hermetikind.*, **30**, 212 (1944).

Johnston, W. W., "The Preparation of Leather Bates from Fish," Fisheries Research Board Canada, *Prog. Repts., Atlantic Coast Stations,* **18**, 11 (1936).

Lovern, J. A., "Present Trends and Future Developments in the Technology of Fish," *Chemistry and Industry* (1947).

Lovern, J. A., "Fish Oils," *Thorpe's Dictionary Applied Chem.*, **5**, 226 (1941).

McLean, D., "Further Observations on Testicular Extract and Its Effect upon Tissue Permeability," *J. Path. Bact.*, **34**, 459 (1931).

McKercher, B. H., "Agarlike Gums and Algin from British Columbia Seaweeds," Fisheries Research Board Canada, *Prog. Repts., Pacific Coast Stations,* **64**, 53 (1945).

Miller, B. F., Abrams, R., Dorfman, A., and Klein, M., "Antibacterial Properties of Protamine and Histone," *Science,* **96**, 428 (1942).

Norris, E. R., and Elam, D. W., "Preparation and Properties of Crystalline Salmon Pepsin," *J. Biol. Chem.*, **134**, 443 (1940).

Puncochar, J. F., "Fish Jaw Oil," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **8**, No. 5, 18 (1946).

Reay, G. A., and Kushel, C. C., "The Proteins of Fish," Food Investigation Bd. Gt. Brit. Rept., **1936**, 93 (1937).

Ripley, P., "Alginate Rayons Are Distinctive New Fibers," *Textile World,* **95**, No. 12, 112 (1945).

Robeson, C. D., and Baxter, J. G., "Neovitamin A," *J. Am. Chem. Soc.*, **69**, 136 (1947).

Scheffer, V. B., "The Commercial Importance of Seaweed Gums in the United States," *Fishery Market News,* **5**, 1 (1944).

Senn, L. F., "Agarweed a Fishing Resource," U. S. Fish and Wildlife Service, *Commercial Fisheries Review,* **8**, No. 8, 1 (1946).

Tarr, H. L. A., "Possibilities of Developing Fisheries By-products," *Food Technology,* **2**, 268–277 (1948).

Walford, L. A., "The Pacific Sardine Industry," U. S. Fish and Wildlife Service, *Fishery Leaflet,* **129** (1945).

Wood, E. J. M., "Sources of Agar in Australia," *J. Council Sci. Ind. Res.*, **18**, 263 (1945).

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